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WATER-SUPPLY

AND

IRRIGATION PAPERS

OF THE

UNITED STATES GEOLOGICAL SURVEY

No. 17-23

IRRIGATION NEAR BAKERSFIELD, CALIFORNIA.—GRUNSKY

WASHINGTON
GOVERNMENT PRINTING OFFICE
1898

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UNITED STATES GEOLOGICAL SURVEY

CHARLES D. WALCOTT, DIRECTOR

IRRIGATION NEAR BAKERSFIELD, CALIFORNIA

BY

CARL EWALD GRUNSKY

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CONTENTS.

	Page.
Letter of transmittal	11
Introduction	13
San Joaquin Valley	15
Water appropriation and irrigation districts	19
Kraft irrigation district	23
Orland South Side irrigation district	23
Central irrigation district	23
Colusa irrigation district	23
College City irrigation district (proposed)	23
Browns Valley irrigation district	23
Modesto irrigation district	24
Turlock irrigation district	24
Madera irrigation district	24
Selma irrigation district	24
Alta irrigation district	24
Tulare irrigation district	24
Tule River irrigation district	25
Tipton irrigation district	25
Poso irrigation district	25
Kern and Tulare irrigation district	25
Huron irrigation district	25
Sunset irrigation district	25
Methods of irrigation	26
Wild flooding	26
Flooding in contour checks	27
Flooding in rectangular checks, not level	29
Flooding in level checks	30
Flooding between parallel levees	31
Furrow irrigation	32
Furrow irrigation of cereals	32
Furrow irrigation of permanent cultures	32
Furrow irrigation in level checks	33
Furrow irrigation of vegetables	33
Irrigation by filling subsoils with water	33
Subirrigation, or irrigation from subsurface conduits	35
Kern River	37
Hydrography	37
Soils and rainfall	41
Canals and ditches	42
Rio Bravo Ranch canals	42
Kern Island Canal	43
Old South Fork	46
Farmers Canal	47
Panama Slough	47
Castro Ditch	48
Fisher & Abley Ditch	48

Kern River—Continued.
Canals and ditches—Continued. Page.
Stine Canal 48
Anderson Canal 48
Gates Canal 49
Buena Vista Canal 49
James Canal 49
Plunkett Ditch 50
Meacham Canal 50
Wilson Canal 50
Henley and Frazier ditches 50
Beardsley Canal 50
McCaffery Ditch 51
McCord Canal 51
Calloway Canal 51
Emery Ditch 55
Jones & Tuckey Ditch 56
Railroad Canal 56
Wible Canal 56
Goose Lake Canal 56
Pioneer Canal 57
Edwards Ditch 58
James & Dixon Canal 58
Johnson Canal 59
Ashe Ditch 60
May Ditch 60
Joice Canal 60
Dixon Canal 61
Kern Valley Water Company's canals 61
Kern and Tulare irrigation district 63
Water supply, distribution, and measurement 64
Methods of irrigating and duty of water 66
Irrigation from Poso Creek 75
Poso irrigation district 75
Irrigation from Deer Creek 76
Wingfield Ditch 76
Carothers Ditch 76
Deer Creek Consolidated Ditch (Sausalito Ditch) 76
Tule River 78
Hydrography 78
Canals and ditches 78
South Tule River Ditch 78
Wilcox Ditch 79
Plano Ditch 79
Vandalia Ditch 79
Rose Ditch 79
Mitchell, Springer & Rose Ditch 79
South Side Tule River Canal 79
Fine Ditch 80
Callison Slough (Woods Central Ditch) 81
Old English Ditch 81
Stockton Ditch 81
Ball & Harris Ditch 82
Empire Ditch 82
Woodville Ditch 82

Tule River—Continued.
Canals and ditches—Continued. Page.
Tipton Ditch 82
Janes Ditch 83
Lone Oak Slough 83
Hively Ditch 83
Creech Ditch 83
Rogers Lower Ditch 83
Fancher Ditch 83
Finney Ditch 83
Swall Ditch 83
Gully Ditch 83
Swall & Weesling Ditch 84
Great American Ditch 84
Pleasant Valley Ditch 84
Pioneer Canal 84
Traylor Ditch 86
Porter Slough 86
Hockett Ditch 87
Wallace Ditch 87
McGee, Putnam & Caldwell Ditch 87
Gilliam Ditch 87
Hubbs & Miner Ditch 87
Fulweiler and Hunsaker ditches 88
Pletts Ditch 88
Thomas Ditch 88
Elrod Ditch 88
Ray & Brown Ditch 88
M. M. Burnett Ditch 88
Bond Ditch 89
Rogers Upper Ditch 89
Rogers Middle Ditch 89
Klein Ditch 89
Lamarsna Ditch 89
Bacigalupi Ditch 89
Bacigalupi & Creighton Canal 89
Tulare Lake Canal 90
Tule River irrigation district 90
Tipton irrigation district 91
Methods of irrigation 92
Pump irrigation at Lindsay 94

LETTER OF TRANSMITTAL.

DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
DIVISION OF HYDROGRAPHY,
Washington, July 1, 1898.

SIR: I have the honor to transmit herewith a manuscript entitled Irrigation near Bakersfield, California, prepared by Mr. C. E. Grunsky, and to recommend that it be published in the series of pamphlets on Water Supply and Irrigation. This paper is the first of three relating to San Joaquin Valley, the others being entitled, respectively, Irrigation near Fresno, California (No. 18 of the series), and Irrigation near Merced, California (No. 19 of the series), these titles being somewhat arbitrarily given to indicate the relative geographic position of the areas described. These papers taken collectively are intended to exhibit the character of the development of irrigation in the southern part of the great valley of California, and to give the methods there employed and the results of the experience acquired through many years.

In this, the first paper, some space has been devoted to a general description of San Joaquin Valley as a whole, and of the irrigation districts which have been organized within it, the history of these being briefly outlined. There is also added a description of the methods of irrigation commonly employed, as this has especial interest in connection with the more detailed statements regarding the individual canals and ditches. Following these more general matters Kern River is taken up, its drainage basin is discussed, and each of the numerous systems of water supply depending upon the river is described at some length. Then the creeks lying to the north, Poso and Deer, are decribed, as well as Tule River.

Although a relatively high degree of development of irrigation has been reached in this part of the arid region, yet the results are far below the possibilities. By means of better methods of water conservation and distribution, and more effective modes of intensive agriculture, the population and wealth of San Joaquin Valley may be almost indefinitely increased. A full discussion, therefore, of this interesting area has value not only as showing what may be, to a certain extent, accomplished elsewhere, but also as illustrating the fact that great progress can still be made in this area.

Very respectfully,

F. H. NEWELL,
Hydrographer in Charge.

Hon. CHARLES D. WALCOTT,
Director United States Geological Survey.

IRRIGATION NEAR BAKERSFIELD, CALIFORNIA.

By C. E. GRUNSKY.

INTRODUCTION.

The historical and descriptive treatment of irrigation in San Joaquin Valley as here presented is based largely upon information collected by the State engineering department of California ten years ago. That department ceased to exist in independent form in 1888. Its work was to be completed by the State mineralogist, who during the next two years was ex officio State engineer, and it was expected that a final report would be published, covering irrigation in central portions of the State, to supplement the two volumes already issued.[1] But the third volume of the final report has not appeared, and much of the collected material has been lost or is in unserviceable form, and none of it is conveniently accessible. Under these circumstances the writer, who, as chief assistant State engineer from 1882 to 1887, had charge of the collection of irrigation data in the field now under consideration, and of its preliminary arrangement for publication, believes it timely to give to the public at least such benefit as may result from a delayed publication of a portion of the collected information. To this end use has been made of what is left of official records, notebooks, sketches, and fragmentary manuscript (principally of the writer's own preparation), taking therefrom and grouping whatever seemed of sufficient importance to justify publication.

The facts obtained from this source have been supplemented by the results of subsequent personal experience in the field, and by accounts of irrigation works and of experience obtained from persons of local prominence, as well as by information secured on a special trip through the region under discussion, made in the spring of 1897.

It remains to be said that portions of the river descriptions and kindred matter have been taken from the report of the Examining Commission on Rivers and Harbors,[2] frequently without credit, as the writer was a member of that commission and author of its descriptive chapters.

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[1] Irrigation Development, History, Customs, Laws, etc., in France, Italy, and Spain, by Wm. Ham. Hall, C. E., State Engineer, Sacramento, California, 1886; and Irrigation in California (Southern), Part 2 of Report of Wm. Ham. Hall, C. E., State Engineer of California, 1888.

[2] Report Examining Commission on Rivers and Harbors to the Governor of California; C. F. Reed, C. E. Grunsky, J. J. Crawford, commissioners; 1890.

It will be made apparent in these papers that irrigation development has been most rapid in those sections of the valley where rainfall is less than 10 inches a year and where water diversion from the streams is readily accomplished. There has been comparatively little irrigation in the great central valley northward from Merced River. This is due primarily to the greater natural fertility of the soils, resulting from more rainfall than in the upper or southern portions of the valley, but also to the fact that the principal rivers are considerably depressed below the general upland level, making the diversion of water for upland irrigation often difficult and always expensive. Vineyards and orchards in the lower portion of San Joaquin Valley and throughout Sacramento Valley yield fairly well without irrigation, and the standard crop, wheat, is rarely a complete failure. Protests have therefore at times been loud and emphatic against attempts to make water for irrigation available at general expense in this part of the great central valley of the State. Notwithstanding the active opposition which becomes manifest whenever the construction of comprehensive irrigation systems, such as would compel a modification of the present use of lands, is suggested, the spirit of unrest, discontent, and a desire to change conditions preponderates in many sections of the northern portion of the great central valley. This was demonstrated when opportunity was afforded to organize irrigation districts under the Wright law ten years ago. Seven out of eight districts proposed to the northward of Merced River were speedily organized. This desire to change from dry farming to the more intense cultivation of the soil made possible by irrigation is evidenced, too, by the success of a number of small irrigation works in and adjacent to Sacramento Valley. Among these are the irrigation ditches from Cache Creek, near Woodland, Moore Canal, Capay Ditch, and Adams Ditch. Thermalito, Palermo, and Orangevale may be cited as localities where the growth of citrus fruits is stimulated by the use of water. There is some irrigation from Stony Creek. Deer Creek supplies water for the great vineyard at Vina. Putah Creek is drawn upon for pump irrigation of a number of orchards and vineyards, and both stream and wind assist in raising ground water to the surface near Florin for the irrigation of orchards, vineyards, and gardens. It is not within the scope of this paper, however, to enumerate or describe the irrigation works of Sacramento Valley, and they are referred to merely as illustrating the gradual growth of sentiment in favor of the irrigated farm. The backset which irrigation has received by the unsatisfactory operation of the irrigation-district law will, it is hoped, be only a temporary check of healthful development under extensive systems of canals that should make much of the water of our best rivers, now flowing unused to the sea, do duty as an aid to agriculture.

The author desires to express his appreciation of the many courtesies extended to him in all parts of the valley in the work of collecting data,

and to thank those who have kindly contributed their knowledge of facts or have otherwise aided him or contributed material for this publication.

SAN JOAQUIN VALLEY.

San Joaquin Valley is the southern and larger portion of California's great central valley which lies between the Sierra Nevada on the east and the Coast Range on the west. Its length, measured along the axis of the valley, from near Stockton at its lower end to the base of the Tejon Mountains at its upper end, is 250 miles. The average breadth of the valley is over 40 miles. It is naturally divided into an east-side plain and a west-side plain, which slope with remarkable uniformity and smoothness of surface from the base of the hills upon either side toward the valley trough. Of these plains, that upon the east side of the valley, at the base of the Sierra Nevada, is by far the more extensive and the more important.

In their original condition the uplands of the valley were almost treeless. A few groves of oaks, some of considerable extent, were confined to the lands watered by Calaveras and Mokelumne rivers and lesser streams near Stockton; to the black land near Merced, principally to that watered by Bear and Mariposa creeks; and to the deltas of Kings, Kaweah, and Tule rivers. Some timber, too, was found on the river bottoms and on the submersible plain near the trough of the valley. Except where cottonwoods, willows, and occasional oaks or sycamores mark the course of the principal west-side creeks, all the unirrigated lands of the west-side plain and the abutting hills of the Coast Range are bare of trees.

The area of San Joaquin Valley is 11,500 square miles, which may be classified as follows: East-side plain, 7,700 square miles; west-side plain, 1,850 square miles; lands covered with water and lands subject to occasional inundation, about 1,950 square miles, of which 300 to over 900 square miles, according to the stage of Tulare Lake, are lake surfaces.

The mountain watershed tributary to the valley, including Cosumnes River, is 20,400 square miles in extent, of which less than one-fifth lies on the west, in the Coast Range, more than four-fifths being to the east, in the Sierra Nevada. Large rivers of perennial flow enter the valley from the east and cross the broad east-side plain, but on the west the numerous small creeks and gulches have no summer flow, and their channels are lost before they reach the main valley drain.

The valley may be considered as again divided into three portions by low, flat ridges built of silt deposits made by two of the principal east-side rivers, Kern River and Kings River, but the lines of demarcation are not features of any prominence. In both cases there has been a gradual pushing forward of the river deltas until basins or depressions

have been formed above the crest line of each, thus giving rise to the Kern and Buena Vista lake basins in the one case and to the Tulare Lake basin in the other.

The former of these basins has never been one of sufficient capacity to prevent the annual outflow of Kern River waters toward the north by way of Buena Vista Swamp into Tulare Lake. The latter, however, repeatedly and for many years at a time, even before there was any diversion of water from tributary rivers for irrigation, has been so insufficiently supplied with water that it failed to overflow. During such periods the entire drainage basin above Tulare Lake, including ordinarily a portion of the flow of Kings River, is not tributary to San Joaquin River, whose watershed area is then reduced to about 19,000 square miles, of which about 7,500 square miles are valley lands, from which there is ordinarily little or no run-off.

Tulare Lake has frequently been under discussion as a source of water supply for irrigation. The following facts with reference to the fluctuations of its water surface will be of interest in connection with its availability for this purpose: In 1853, after several wet seasons, the lake was full, though probably not so high as subsequently, in 1862 or in 1868. From 1853 until 1861 there was a gradual subsidence of the low-water stage of the lake. The rate at which this occurred can not now be determined. In the fall of 1861 the water surface of the lake was at the elevation 204 feet above sea level (low water of Suisun Bay), if the testimony of residents at the lake at that time, in reference to the rise of water the following winter, can be relied upon. The unusually heavy rainfall of the winter of 1861–62 caused the lake to rise to the highest known stage—220 feet. Its area was increased from about 300 to about 800 square miles, and 300 billion cubic feet, or 6,885,000 acre-feet, of water were added to its contents. It continued to overflow at least until the spring of 1863, but then rapidly fell to about 11 or 12 feet below its highest stage, which was its condition in the fall of 1867. The inflow of water during the wet winter of 1867–68 again brought the lake nearly, if not quite, to the high-water stage of 1861–62.

The water surface fluctuated between 211 and 217 feet in the years 1872 to 1876, then receded rapidly to the lowest known stage—192 feet—in November, 1883. From that time to this the lake has not received sufficient water to cause it to overflow. It is generally believed that the diversion of water for irrigation purposes from Kern, Tule, Kaweah, and Kings rivers has been the cause of the decrease of water volume in the lake, but this is not true. Although such diversion must produce some effect on the lake, the evidence that protracted low stages preceded the low stage of 1883 is conclusive. On the northeastern shore of the lake, close by the mouth of Mussel Slough, there is a group of tree stumps at an elevation of about 200 feet. These were found at the water's edge in 1882. They presented the appearance of having been broken off at a height of 3 to 4 feet above ground. They were

PRINCIPAL RIVERS OF CALIFORNIA

SCALE

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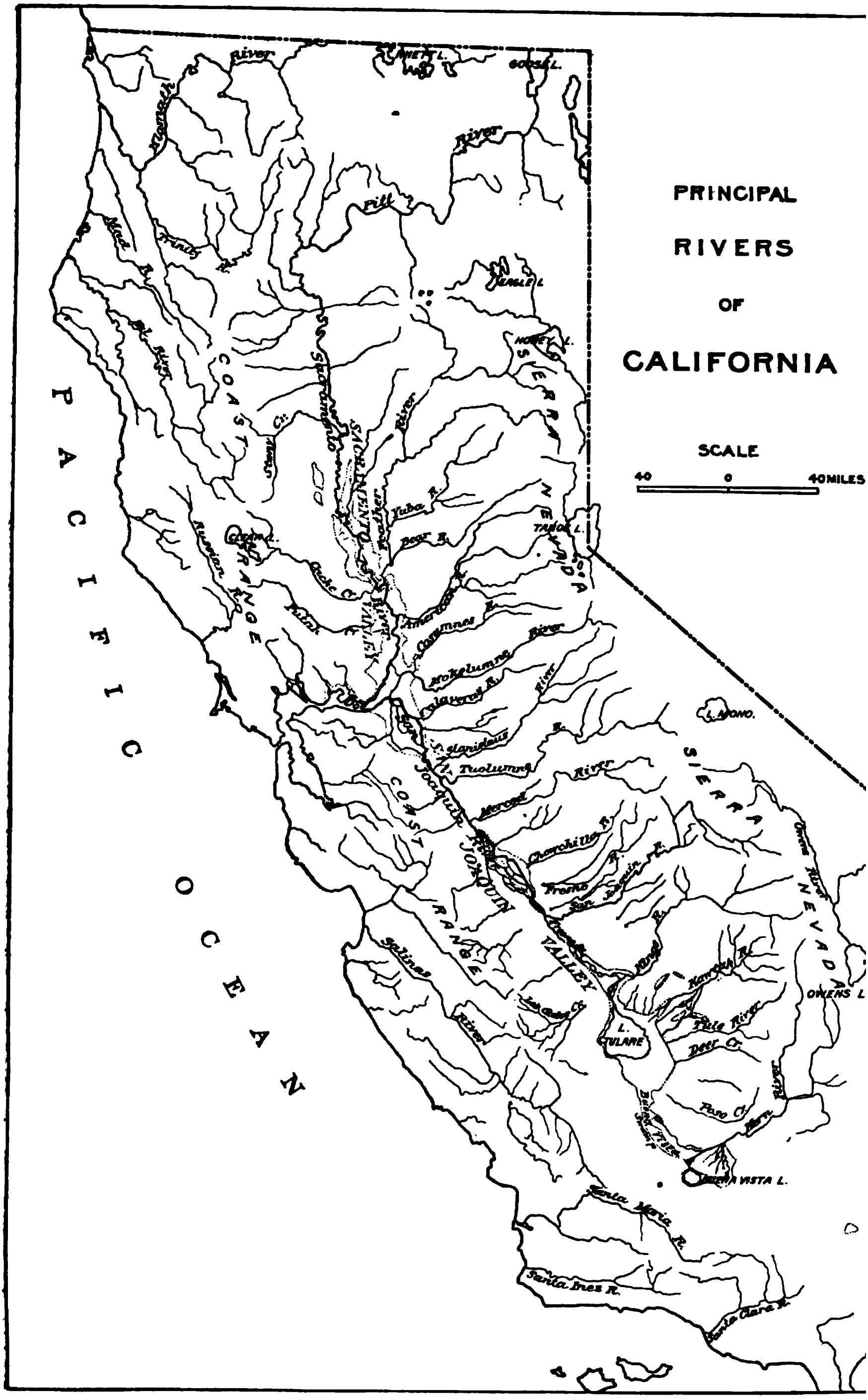


well preserved and must have been under water for nearly thirty years succeeding the high stage of the lake of 1853. These stumps are a remnant of a grove of willow trees, 100 or more, some of which had grown to a diameter of 4 feet. It would not have been possible for these trees to attain such growth if the lake had not been at a low stage for many years in succession at some time preceding 1853. Moreover, Indian tradition is said to indicate a time when the lake was contracted to two ponds, between which a passage from the east to the west side of the valley was possible.

The lowest portion of San Joaquin Valley is but slightly elevated above sea level. The elevation of the surface of the ground is from 10 to 20 feet along the eastern margin of the main body of submersible land in the lower end of the valley. Thence the trough of the valley southeastward gradually rises to 214 feet on the flat saddle below Tulare Lake. The elevation of the lowest point in the bottom of Tulare Lake is about 175 feet; and thence there is a rise of about 120 feet to the outfall point of Buena Vista Lake. This lake and Kern Lake occupy the lowest portions of the depression above the Kern River ridge, and their beds are at the elevation of 285 feet.

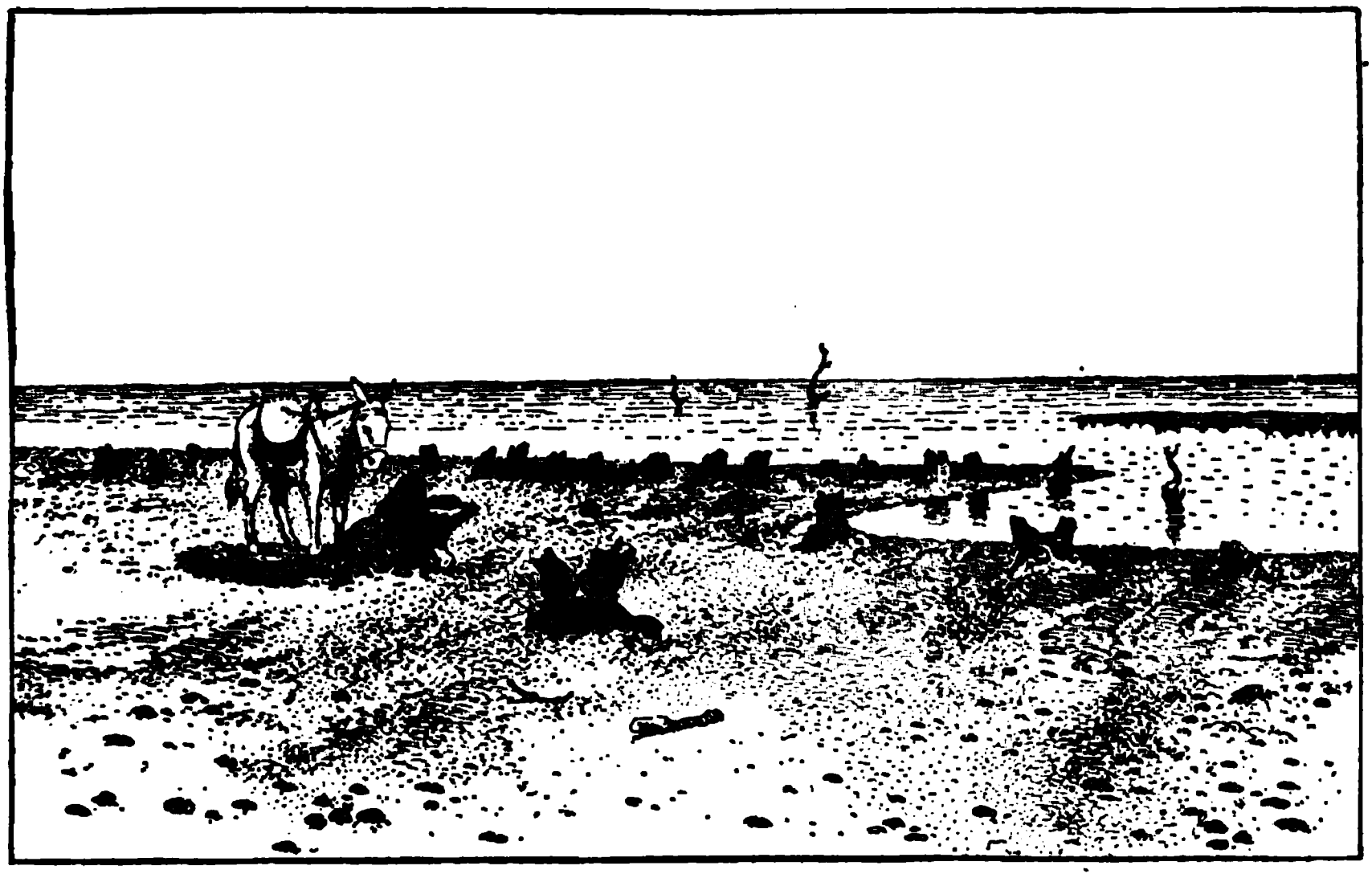


FIG. 1.—Tulare Lake, near mouth of Mussel Slough, 1882.

The eastern edge of the valley rises from an elevation of 110 feet, opposite Stockton, to 500 feet southeastward from Bakersfield. The slope of the east-side plain is from the hills toward the valley trough at the rate of 5 to 10 feet a mile; that of the west-side plain is somewhat greater. Except for the bad-land or alkali strip, of variable width, which flanks the submersible lands of the valley, the entire valley may be considered as well adapted for irrigation so far as soils and physical conditions are concerned.

The Division of Hydrography of the United States Geological Survey has maintained a number of gaging stations in San Joaquin Valley, and has published some of the results.[1]

The important streams which flow into San Joaquin Valley are all Sierra Nevada streams. They appear in small capital letters in the following list of rivers and creeks which are tributary to the valley:

	Area drained, in square miles.
From Tejon Mountains:	
Tejon Creek	64
Tecuya Creek	40
Arroyo Plata	32
San Emidio Creek	69
From the Sierra Nevada:	
Caliente Creek	423
KERN RIVER	2,345
Poso Creek	289
White River	90
Deer Creek	110
TULE RIVER	437
KAWEAH RIVER	619
KINGS RIVER	1,742
SAN JOAQUIN RIVER	1,637
Fresno River	272
Chowchilla River	268
Mariposa Creek	122
Bear Creek	166
MERCED RIVER	1,076
TUOLUMNE RIVER	1,501
STANISLAUS RIVER	1,051
Calaveras River	491
MOKELUMNE RIVER	657
Dry Creek	283
COSUMNES RIVER	580
From the Coast Range:	
Los Gatos Creek	441
Cantua Creek	52
Big Panoche Creek	289
Little Panoche Creek	106
Arroyo Ortigalitos	64
Los Banos Creek	151
San Luis Creek	88
Romero Creek	24
Quinto Creek	29
Las Garzas Creek	57
Orestimba Creek	142
Arroyo de la Puerta	77
Arroyo de los Piedras	20
Hospital Creek	30
Corral Hollow Creek	73
Marsh Creek	54

[1] Twelfth Ann. Rept. U. S. Geol. Survey, Part II, 1891, pp. 316–323, Pls. LXXX–LXXXVIII; Bulletin No. 131, 1895, pp. 78–86; Bulletin No. 140, 1896, pp. 256–314; Eighteenth Ann. Rept. U. S. Geol. Survey. Part IV, 1897, pp. 371–396; Water-Supply and Irrigation Paper No. 11, 1897, pp. 90–92; Water-Supply and Irrigation Paper No. 16, 1898, pp. 187–192.

WATER APPROPRIATION AND IRRIGATION DISTRICTS.

It is provided in the constitution of the State of California adopted in 1878 that "the use of all water now appropriated, or that may hereafter be appropriated, for sale, rental, or distribution," is a public use, subject to regulation and control by the State, and that water rates are to be fixed annually by the governing bodies of counties and municipalities.

The civil code of the State says: "The right to the use of running water flowing in a river or stream or down a canyon or ravine may be acquired by appropriation." But this right ceases when the water ceases to be applied to some useful or beneficial purpose. As between appropriators, the one first in time is the first in right.

The method of making an appropriation and of giving notice of the water claim is thus prescribed:

> . . . person desiring to appropriate water must post a notice, in writing, in a conspicuous place, at the point of intended diversion, stating therein: (1) That he claims the water there flowing to the extent of (giving the number) inches, measured under a four-inch pressure; (2) the purposes for which he claims it, and the place of intended use; (3) the means by which he intends to divert it, and the size of the flume, ditch, pipe, or aqueduct in which he intends to divert it. A copy of the notice must, within ten days after it is posted, be recorded in the office of the recorder of the county in which it is posted.

But the mere posting and recording of this claim to water confers no right upon the appropriator unless, within sixty days after the notice is posted, the construction of works is commenced and diligently prosecuted to completion. In that event, and in that only, are rights acquired, which then relate back to the time the notice was posted. Moreover, the water right secured under the notice and by construction of works should not be considered to be that defined in the notice, wherein the amount named is often absurdly exaggerated, or may be wholly unintelligible; but regard is to be had to the works and their capacity as actually constructed in interpreting the language of the claim.

Whole volumes have been filled in some of the counties of this State with records of claims to water, but there is no department of record—except the courts in cases of conflict—in which the facts relating to date of ditch or canal construction, location, dimensions, and capacity are or can be preserved. Where the recollection of the oldest inhabitant is often the only source of information, it is extremely difficult to trace the history of irrigation works, and information obtained from owners must be treated with some caution.

This condition of public records in the matter of water appropriation should be remedied at once. The State needs a permanent department whose duty it will be to determine the necessary facts, as well as may be, with reference to every water appropriation and to define the rights

of the several appropriators. There are, of course, many other duties with which such a department might be charged, but it is not proposed to enlarge upon the matter at this time.

After defining the method of appropriating water, as above explained, it was until 1887 further provided in the civil code that "the rights of riparian proprietors are not affected by the provisions of this title." Notwithstanding the repeal of this particular section of the code, all appropriations of water must necessarily remain subject to whatever rights are vested in the bank-land owners.

The first attempt to combine ownership of land and control of water for irrigation in corporations with municipal functions appears in an act to promote irrigation, which was approved by the governor of California on April 1, 1872. This act was a precursor of the irrigation-district law now in force, and provided for the formation of irrigation districts on petition of land owners, and for the construction of works with money secured by assessment of benefits upon the lands in the districts. The affairs of the districts were to be managed by boards of trustees.

This law was restricted in its operation to a part of the State, and remained practically inoperative. Four years later a special law was passed authorizing the formation of the "West Side irrigation district," for which elaborate surveys and studies were made and which was to have been largely dependent upon Tulare Lake as a source of supply. Notwithstanding the recommendation of its engineers and of the commissioners in charge of the matter, the project failed, and district control of water for irrigation purposes was again deferred until the Wright law (named after its author, Mr. C. C. Wright, of Modesto) was passed, in 1887. Much has been hoped from this new law authorizing the formation of irrigation districts. The prime object of the law is to unite ownership of land and water. It is provided that, upon a petition of landowners, lands susceptible of irrigation by the same system of works may be included within the bounndaries of a district, which, upon ratification by a vote of the electors therein, is endowed with municipal functions for the specific purpose of securing and distributing water for irrigation.

The affairs of each district are managed by a board of directors, one of whom is elected from each of the five divisions into which the district is ordinarily divided, and until recently amended the law required that each director must be a resident of the particular division of the district by which he was elected. These requirements have recently been modified to the extent that, on the basis of the petition for the formation of the district, only three divisions may be formed, and that the election of the directors may be at large. This was done to overcome difficulties encountered in finding suitable persons to serve as directors in sparsely settled districts. Powers are conferred upon the directors to do everything that may be necessary to carry out the intent of the law and to secure and distribute the

water required for their respective districts. As soon as the probable cost of the works is determined they fix the amount of bonds necessary to be issued, and the question of bond issue is submitted to the qualified electors of the district. Work on district canals is ordinarily done by contract, but may also be done by day labor. It was originally prescribed by law that bonds should not be sold at less than 90 per cent, and as the law now stands no sales are to be made at less than par. The bonds may also be used in paying for completed canals and for water rights and rights of way, but are not to be used for defraying expenses of operation and management.

Difficulties were soon encountered in the application of this law. Almost at the outset it was found that when the exterior boundaries had been fixed by the county supervisors on petition of landowners and the testimony of volunteer witnesses, there was no certainty that correct conclusions had been reached, and the irrigation project assumed to be feasible in advance of an engineering investigation might still be grievously at fault. When taxes were to be collected to meet expenses of examination and surveys, active opposition often became manifest and payments were in many cases greatly delayed. The validity of the law was called into question and was passed upon repeatedly by State courts, and finally by the Supreme Court of the United States, which only recently rendered the decision which conclusively established its validity.

Meanwhile many of the districts which commenced operations under favorable auspices had adopted plans and issued bonds which had been offered for sale with more or less success. The hope that full confidence in the successful operation of the law would be speedily established and that the 6 per cent bonds would soon sell above par was not realized, and despite favorable decisions in the superior courts, confirmatory of the proceedings in individual districts, and favorable action by the supreme court of the State, the bonds did not sell readily. The districts that had been most active in pushing the work on their canals then found themselves in a somewhat peculiar position. The construction funds maintained by the proceeds of bond sales were depleted, the canals and structures were incomplete and of no use until completed, and to current expenses had been added the annual interest and sinking fund account on bonds already sold.

It is hardly surprising that, pending a final decision by the highest tribunal of the country—a decision which was not secured until nine years after the enactment of the law—every resource was exhausted by some of the district managements to continue operations and to derive benefit from completed or nearly completed works. The law requiring bonds to be sold at 90 per cent or more was, in some instances, evaded by selling without requiring the purchaser to guarantee that bonds would be taken as offered. Contracts were then awarded, often without more than nominal competition, and at rates far [illegible] of

cash value, it being generally understood that the money paid in for any block of bonds quickly returned to the contractors, in exchange for warrants for work performed or material furnished. In other cases ditches were built under supervision of the district engineer by private parties, and after completion were bought by the irrigation district for bonds, which were thus legally disposed of without a direct sale. The cost of works under such conditions necessarily became greater than if all could have been constructed for cash. Sometimes, too, first estimates of cost were too small to complete the system of works even under ordinary conditions, so that supplemental bond issues had to be resorted to, or will yet be necessary, to complete and put the irrigation systems into service.

It is found, too, that the introduction of water into a new district generally brings disappointment. The farmer is not prepared to make immediately full use of the water. Its mere presence in the main canals and laterals is not a guaranty of good crops, and he is often slow to adapt himself to the new methods of farming that become necessary. So the burden put upon the farmer in the shape of increased taxation brings no quick return, and, even under comparatively favorable conditions, dissatisfaction is likely to result.

In the light of ten years' experience the conclusion seems justified that, though endeavoring to establish a correct principle, the law has not been uniformly successful in its operation. State supervision by a competent board of public works, which has the confidence of the people, is a first requirement. This supervision should not be a mere nominal one, but district boundaries and preliminary plans of works should emanate from a department of that character, and no plans should be finally adopted without its approval. Such board should serve the several districts at least in an advisory capacity when required to do so, thereby guaranteeing, as far as may be possible, an adequate source of water supply and an adequate canal system. The bonds of every district should be guaranteed by the State, and all bond sales should be made by the State, so that district construction work may always be done on a cash basis.

Bond issues, after being declared necessary by the directors of any district, are voted upon by the qualified electors of the district. Operations under the law would have been safer and would have commanded greater confidence if the right to vote on all questions involving the expenditure of money or the incurring of an indebtedness could have been restricted to the landowners or the taxpayers of each district. The question of material benefit would in most cases be safer in their hands than if left to a popular vote, which, as the law now stands, is often largely cast by a floating population.

Under the district law the operating expenses are raised either by the levying of an assessment (which must be ratified by a vote) or by charges established by the directors for the use of the water.

There are several irrigation districts in San Joaquin Valley in which canal systems have been brought into actual service, but, as above intimated, the operation of the system does not give general satisfaction. The irrigation districts of the great central valley of California are here briefly enumerated. Those of San Joaquin Valley will again be taken up and treated more fully in connection with the irrigation works dependent upon a common source of supply.

Kraft irrigation district.—This is the most northerly of the several districts in Sacramento Valley, and is situated on the north side of Stony Creek. It was organized in 1888. Its area is 13,500 acres. Stony Creek was to be the source of supply, and bonds to the extent of $80,000 were voted. No bonds were sold, all debts were paid, and no further action under the law is contemplated.

Orland South Side irrigation district.—This district, in Sacramento Valley, was organized in 1888 and is situated on the south side of Stony Creek, directly opposite Kraft district. It has an area of about 26,000 acres and was to be dependent upon Stony Creek for a water supply. No bonds were sold, although $100,000 had been voted. The district organization is dead.

Central irrigation district.—This is the most important district in Sacramento Valley. It extends southerly from near Stony Creek for a distance of about 40 miles, being situated on the west side of the valley, between the base of the Coast Range foothills and the valley trough, and having an average width of about 4 miles. Its area is 156,550 acres. Sacramento River is the contemplated source of supply. The district was organized in 1887. Estimated cost of works, not including rights of way or litigation, was $538,000. Bonds were issued to the extent of $750,000, of which about $200,000 remain unsold. No work has been done since 1891.

Colusa irrigation district.—This is a Sacramento Valley irrigation district, which has remained inactive. It was organized in 1888, on the west side of Sacramento River, intermediate between the river and Central district. Its area is about 100,000 acres, and the bonds voted were $600,000, but no bonds were sold. The proposed source of water supply was Sacramento River, it being intended to use the upper section of a main canal in common with Central irrigation district.

College City irrigation district (proposed).—This was to be a third district, dependent upon the canal which was to divert water from Sacramento River for Central district. Its organization was under contemplation in 1889, but it failed. It was practically a proposed southward extension of Central district.

Browns Valley irrigation district.—This irrigation district, organized in 1888, is situated in the foothills of the Sierra Nevada, on the east side of Sacramento Valley. It has an area of 43,000 acres. Water for its irrigation is diverted from Yuba River. The bonds voted and sold

amount to $110,000. The irrigation system was completed and is in service.

Modesto irrigation district.—This district is situated in San Joaquin Valley, between Stanislaus and Tuolumne rivers. It was organized in 1887 with an area of about 120,000 acres. To cut down cost of works necessary for its irrigation this area was reduced to 81,500 acres by omitting high uplands in the northeastern portion of the original district. After protracted conferences with Turlock district an arrangement was entered into whereby the two districts were to construct a great masonry weir or diverting dam in Tuolumne River in common, the cost of which was to be apportioned to the two districts in equal shares. The district voted bonds to the amount of $800,000 in 1888, which have all been disposed of. A further bond issue of $350,000 has been voted to complete the main canal and to construct distributaries.

Turlock irrigation district.—This irrigation district is situated on the south side of Tuolumne River and embraces the greater portion of the upland or east-side plain of San Joaquin Valley between Tuolumne and Merced rivers, of which the former is to be the source of water supply. It has an area of 176,000 acres. Bonds to the amount of $600,000 were voted soon after the organization of the district, in 1887, and construction work was actively pushed. A second issue of bonds, to the amount of $600,000, was found necessary, and the main canals will probably be completed within a reasonable time.

Madera irrigation district.—This district, organized in 1888, is situated on the east side of San Joaquin Valley to the north of San Joaquin River. Its area is 305,000 acres. San Joaquin River was to supply water for the district. Bonds to the amount of $850,000 were voted, but none were sold. After much litigation it was finally decided to abandon all further proceedings under the district organization.

Selma irrigation district.—The lands watered by Fowler Switch and Centerville and Kingsburg canals have been united in Selma irrigation district. They are situated on the east-side San Joaquin Valley plain, on the north side of Kings River. It was proposed to acquire by purchase the two canals mentioned. The district was organized in 1890. Bonds were to be issued to the amount of $1,000,000, but this bond issue was twice defeated.

Alta irrigation district.—This district is situated on the south side of Kings River, and has an area of 130,000 acres. It was organized in 1888, and bonds to the amount of $675,000 were voted, of which $410,000 were paid for the "Seventy-six" canal system, which has thus become the district canal. Its water comes from Kings River. Permanent head works and a number of distributing canals are yet to be constructed.

Tulare irrigation district.—This district lies in the delta of Kaweah River, encompassing the town of Tulare. It was organized in 1889, and

FLUME ACROSS ST JOHNS CHANNEL, TULARE IRRIGATION DISTRICT

has an area of 39,200 acres. Bonds to the amount of $500,000 were voted, of which about $300,000 were paid for existing canals, reservoir site, and water rights, and the remainder went toward the construction of branch canals. Kaweah River is the source of water supply.

Tule River irrigation district.—This district is situated in the delta of Tule River. Bonds were originally voted to the extent of $90,000, and a second issue of $10,000 soon followed. This district was organized in 1891. It has an area of about 22,000 acres and takes water from Tule River.

Tipton irrigation district.—This district is situated to the south of Tule River, from which it was to be supplied with water. The bonds voted amount to $50,000. These bonds and unpaid warrants to the amount of $15,000 were necessary to complete a canal system, which is temporarily out of service by order of the court.

Poso irrigation district.—This is another of the east-side San Joaquin Valley districts. It is situated in Kern County, northward from Kern River, on the north side of Poso Creek, which is its source of water supply. It has an area of 40,000 acres, and bonds were voted to the amount of $500,000. It is one of the districts in which land is almost valueless without irrigation. Its sparse population is indicated by the fact that only 24 votes were cast on the question of district organization, and only 35 on the bond issue. Works are still incomplete, though a portion of the district has water. All bonds have been disposed of.

Kern and Tulare irrigation district.—This district lies in Kern and Tulare counties. It was organized in 1890, and was to have been supplied with water diverted from Kern River. Its area is 84,300 acres. The bonds voted amounted to $700,000. Although about $40,000 were expended in preliminary work, there has been no canal-construction work done by the district.

Huron irrigation district.—This is a west-side district, situated near the base of the Coast Range foothills, to the northwest of Tulare Lake. The district was organized in 1891, and was to be irrigated with water developed largely from the subsurface flow of Los Gatos Creek. It has sold no bonds, and no construction work has been done.

Sunset irrigation district.—This is a very large district, embracing a long, narrow strip of land on the west side of San Joaquin Valley. It extends northward from Tulare Lake about 60 miles, and has an area of 363,400 acres. It was organized in 1889. Bonds were voted to the amount of $2,000,000, and some of these have been issued in return for water rights and rights of way. A contract has been let aggregating $1,500,000 for the construction of its works, and operations under it were to begin soon after a favorable decision on the district law by the Supreme Court of the United States. It is understood that the contractor is now ready to proceed under his contract.

METHODS OF IRRIGATION.

Although water was used for the irrigation of mission gardens in California more than one hundred years ago, irrigation may still be regarded as a new art in this State. Irrigation development was not rapid until within the last twenty years, and methods of irrigation are the result in most cases of attempts to adapt to local conditions the methods in use elsewhere. There was no incentive at the outset to prevent waste, so that the method adopted was very often determined by first cost of land preparation. As the duty of water was gradually raised and the supply allotted per acre of land became smaller, more attention was given to the method of use, and particularly to the reduction of waste. The degree of attention which the suppression of waste receives depends also upon the value of the products of the soil. This has led to the introduction of extensive pipe systems in southern counties of the State for water distribution to irrigators, as well as its delivery on individual tracts at the exact spots where wanted for use. But in San Joaquin Valley, where the volumes of water under control are larger and cultures are generally on a lower scale of value than farther south, the use of pipes is still out of the question. The methods here adopted are more or less perfectly adapted to the peculiarities of climate, soil, and physical features of the tracts irrigated, but vary within wide limits according to the caprice of the individual irrigators.

The methods of irrigation in San Joaquin Valley may be classified as follows:

Irrigation by flooding.
Irrigation from furrows.
Irrigation by saturation of subsoils.
Irrigation from subsurface conduits.

Cereals are generally irrigated by flooding or by saturation of subsoils, sometimes by the furrow method; alfalfa is irrigated by flooding or by saturation of subsoils; fruits and vines are irrigated by any of the methods enumerated; and vegetables, generally from furrows.

Wild flooding.—Water is made to escape over the banks of small ditches constructed on the highest ground, and is controlled in its flow over the surface to be irrigated by attendants. The supply ditch is either at the highest margin of the tract to be irrigated or follows along ridge summits. Water is turned from it into irrigating ditches, which are usually very shallow depressions with flat embankments on their lower sides, over which the water flows in a thin sheet. It is controlled as much as possible by attendants, who try to force it over the entire surface intermediate between irrigating ditches. Surplus water accumulates in the lower ditches and is used again. The preparation of the ground for irrigation by wild flooding is very inexpensive, but the cost of applying the water, owing to constant attendance

required, is relatively great. One attendant is expected to irrigate from 1 to 2 acres a day. The irrigating ditches and their embankments are usually so flat that they do not interfere with farming operations. This method of irrigation is to be regarded as somewhat primitive and is used but little.

Flooding in contour checks.—The land to be irrigated is divided into compartments or checks, each of which is entirely surrounded by embankments of earth. The principal embankments follow contour lines, the vertical distance from one contour levee to the next being uniform. The contour interval usually selected is 6 to 9 inches, rarely so great as 1 foot. It depends in all cases upon the surface slope of the ground to be prepared for irrigation, and should be less than 6

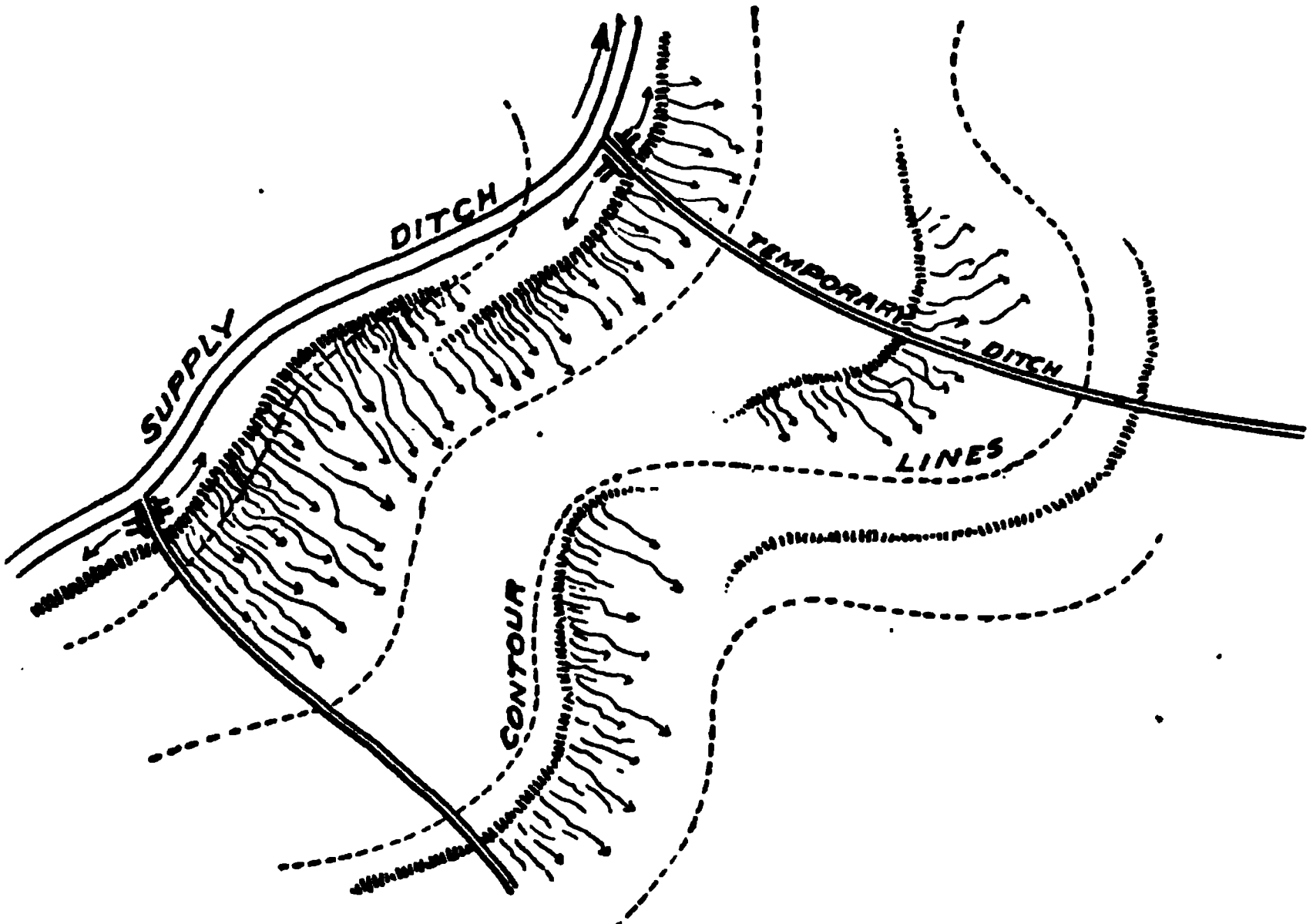


Fig. 2.—Wild flooding.

inches if the ground is sufficiently flat to permit such an arrangement without making the individual checks too small. For ground on a slope that would require levees more than 1 foot apart in elevation some other method of irrigation should be adopted. The strips of land between the contour levees are subdivided by cross levees into compartments of convenient size, which are generally called "checks." Their area should vary according to the volume of water available, a good rule for porous soils being not to exceed one-fourth of an acre for each second-foot when a large head of water is available, and to make half an acre per second-foot the limit for a small supply.

Water is supplied to the several checks in turn from highest to lowest in each series between cross levees. The irrigating ditch which

leads off from the supply canal is usually carried in the direction of greatest slope, cutting the several contour levees nearly at right angles. Irrigation commences by turning a full head of water into the upper check upon one side of the irrigating ditch. This should be filled in from one to six hours. In the full check water should be barely over the highest portion of the ground, but 6 inches to 1 foot deep in the lowest portion of the check, according to contour interval. The contour levee should have its top about half a foot above the water surface of a full check. When the upper check is entirely submerged, gates are opened from the irrigating ditch into the next lower check, those admitting water to the upper check are closed, and one or more

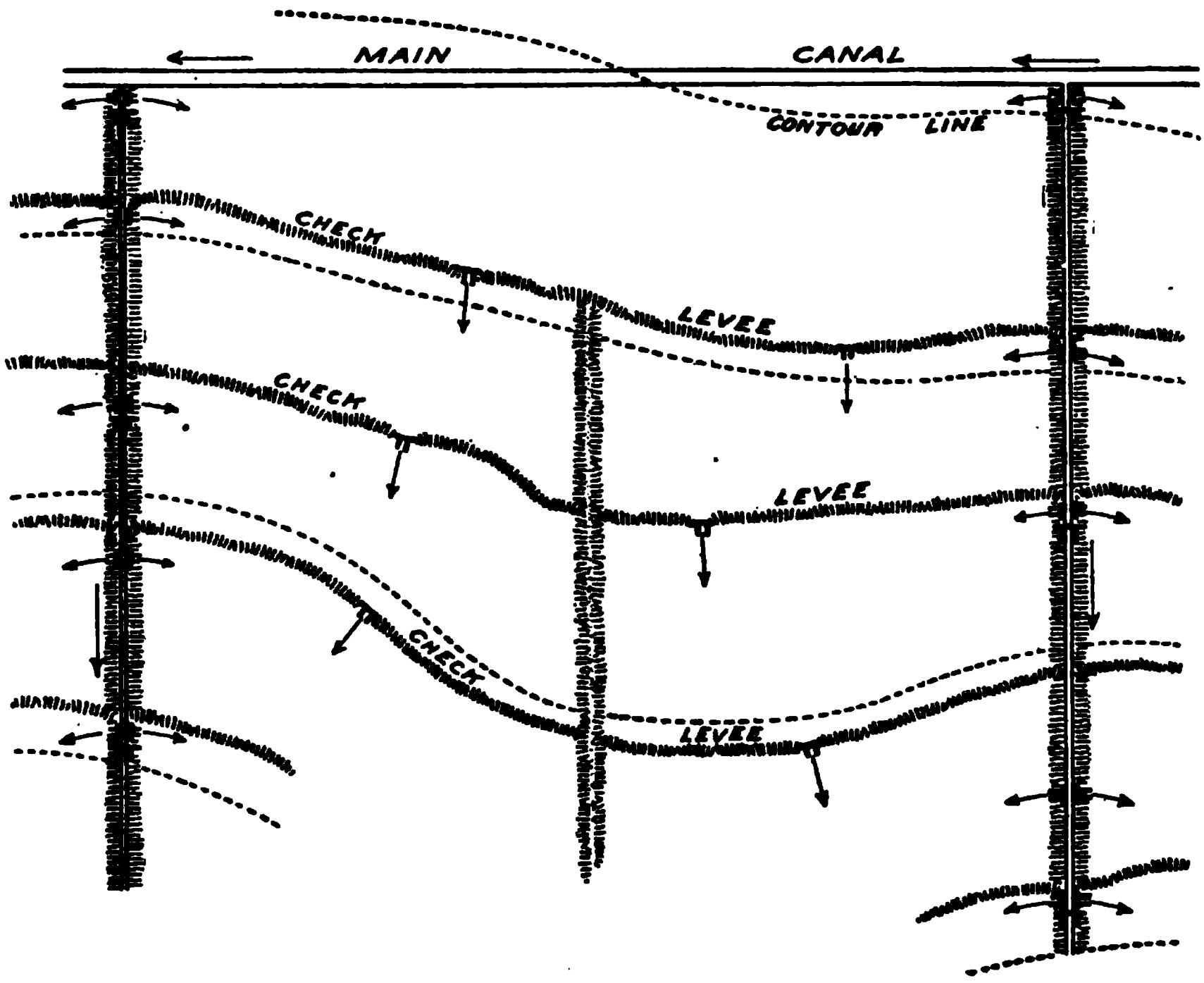


FIG. 3.—Flooding in contour checks.

gates in the contour levee between the two checks are opened to permit the surplus water from the first to drain into and assist in submerging the second one. This will require less time to fill than the first, because the supply of water from the ditch is augmented by the run-off from the upper check.

The irrigating ditches frequently replace cross levees, so that water can be admitted to a check from both sides at once.

When the average time required to fill checks on sandy soils exceeds three hours, it may generally be assumed that water is wasted; either the checks are too large or there is not enough water turned in. Heavy soils, however, do not take up water rapidly, and, aside from requir-

IRRIGATION BY CHECKS IN SAN JOAQUIN VALLEY

ing more time to absorb water, they do not permit its flow to subsoils so readily as do sandy soils, consequently more time may be allowed to fill a check in clayey soil without undue waste. Twenty-four hours should be regarded as the permissible limit.

Checks are occasionally very large. One was found in service under the Calloway Canal having an area of 60 acres. The water supplied to it was reported to have been as great as 250 second-feet. Such areas in one check are never advisable and are merely temporary features of a growing system. Eight to 10 acre checks are large, and those of 2 to 5 acres are generally preferred.

Embankments around the checks may be either permanent or temporary. The latter are rare. Permanent check levees are made of two types, either with very steep sides and narrow tops, so as to occupy as little space as possible, or very broad and flat, so as not to interfere with farming operations. The flat embankment becomes a part of the cultivated area and generally is the most productive part of the irrigated field. It is constructed by scraping up material from a broad area on both sides if the ground is nearly level, or from the lower side only if the ground is comparatively steep. The cost of preparing land for this method of irrigation in permanent checks ranges from $2.50 to $5 per acre, the cost of the necessary distributing canals, ditches, and structures from $3 to $5 per acre. These figures, of course, may be greatly exceeded if the ground has too great a slope or is very much broken by hogwallows, or swales and ridges. Irrigation by this method is much less expensive than by wild flooding. The only work required of attendants is the opening and closing of gates and the guarding of the check levees. When ground is well prepared for this method of irrigation and the supply of water is abundant, the cost of each application of water will range from 3 to 30 cents per acre. The best examples of irrigation by this method are found on Kern Island; under Calloway Canal; on Buena Vista farm, watered by the Kern Valley Water Company's canals; near Borden and Madera; on the Riverside, Columbia, and Chowchilla ranches, irrigated by the Chowchilla Canal; on the west side of the San Joaquin, under the San Joaquin and Kings River Canal; and at various other points.

Flooding in rectangular checks, not level.—The subdivision into compartments of the land to be irrigated is carried out on straight lines, and levees are built on these lines. The subdivision may be planned with some regard to the direction of the contour lines and lines of greatest slope, or these may be entirely ignored. The advantage of this system over subdivision or contour lines is better conformity with property limits and culture borders, but it has many disadvantages when the surface of the ground is not very smooth. Levees are not uniform in dimension, as is the case with the principal levees under the contour system. It is difficult to avoid leaving low spots, which interfere with thorough drainage, and the first cost of land preparation is

generally somewhat greater than when contour levees are used. The method of applying water is substantially the same as in the case of contour-check irrigation. Flooding progresses in the direction from highest to lowest ground.

A good example of this method of irrigation is to be seen on the Kohler, West & Minturn tract, near Minturn. The soil is a light, sandy loam, underlain by a hardpan, which is near the surface at the eastern limit of the tract, but which dips westward. The soil water is about 14 feet below the surface. When irrigation is in progress with a full head of water (about 16 second-feet is so considered by its owners), six men are required to manipulate gates and guard check levees. These attendants work in two shifts of three, each for twelve

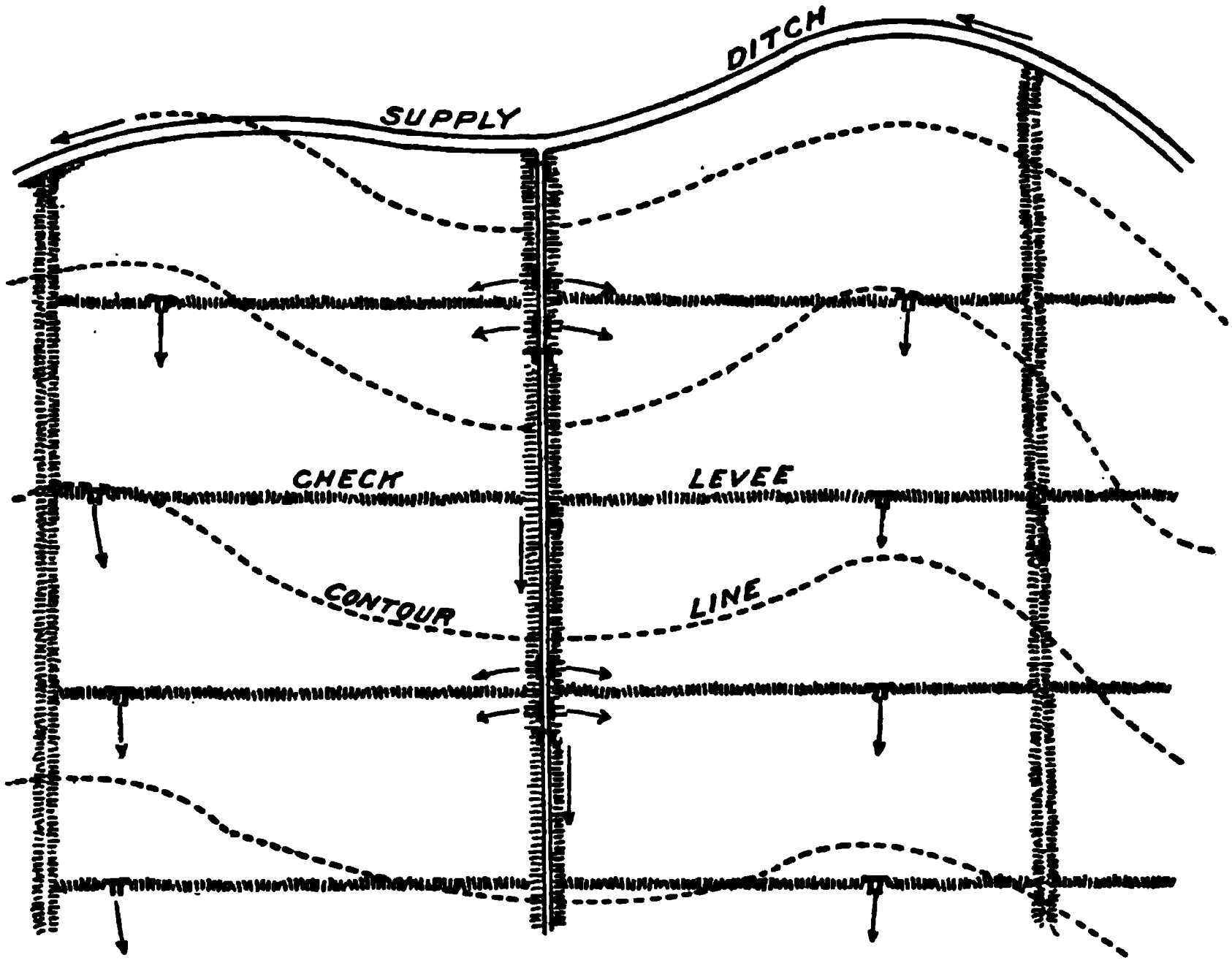


FIG. 4.—Flooding in rectangular checks, not level.

hours. The progress made is at the rate of about 20 acres a day. On the same tract some land is subdivided on the contour plan. Where this is the case the rate of progress is nearly twice as great, but this difference in the duty of water is not to be ascribed solely to the method of irrigation; the rectangular checks are in the western portion of the tract, where soil is lightest and deepest, and where duty of water is naturally least.

Flooding in level checks.—The surface of the ground in each compartment is made perfectly level and smooth. In such cases the check levees are low. Checks are made small to reduce cost of land preparation. The amount of material to be moved when the original surface is

smooth increases with the square of the dimension of the checks in the direction of greatest slope. All checks are usually made rectangular. Land preparation for this method of irrigation is always expensive, but where the surface needs special treatment, as in the case of the knolly or "hogwallow" lands, the excess of cost over other methods is inconsiderable. The first irrigators near Fresno adopted this method, and it has long remained in favor in that locality. The first application of water was often accompanied by peculiar phenomena, notably in the nature of an irregular surface settlement, due in part to a copious flow from the surface into subsoils, which often caused a general breaking down of the surface. In refilling the depressions caused by the first wetting a level plane was established for each check, regardless of the nature of the crop to be irrigated, and this system of leveling the ground in each check has become a characteristic feature of irrigation near Fresno.

The area of the checks is made small, generally less than 1 acre, usually one-quarter to one-half acre. Water is admitted to the several checks from small irrigating ditches, and is shut off as soon as it has spread over the whole surface of each. There is ordinarily no drainage from level checks. All water admitted to each is allowed to sink into the soil. Not more than three hours should be required to fill a check with water, soil being ordinary sandy loam. If more time is required the supply of water should be increased or the size of the check should be reduced.

In 1882 an irrigator near Fresno was observed irrigating four small checks of alfalfa. His water supply was small, only 2.26 second-feet. Instead of turning all the water in turn into the several checks, he apportioned it to the four, and the time to fill them was ten hours, whereas not more than an hour apiece would have been required had they been filled one after the other.

The cost of preparing land for this method of irrigation, including the necessary small ditches and gates, ranges from about $15 to $50 per acre. The cost of applying water is inexpensive. The attendant in charge usually has time for other work, it being ordinarily only necessary to turn the water off and on.

Flooding between parallel levees.—This is a recent modification of the primitive system of wild flooding, especially adapted to such cultures as alfalfa and growing cereals. Low parallel embankments, generally 50 to 100 feet apart, are constructed in the direction of the land's greatest slope. Water is delivered, at the upper end of a strip of land between two of these embankments, into a ditch whose downstream bank is usually raised slightly above the general surface of the ground, and is made level. Enough water is admitted to this ditch to cause an overflow of 1 to 2 inches over this bank, and this overflow is maintained until water reaches the lower end of the strip of land. Ordinarily the water will spread from levee to levee. If it shows too great tendency

to concentrate on fixed lines, and fails to spread, it is intercepted with other ditches or depressions similar to the one at the head of the strip of land, and the flow from levee to levee again becomes uniform.

All embankments are ordinarily very low and flat, so that farming operations will not be interfered with. The cost of land preparation for this method is about $5 to $10 per acre.

Furrow irrigation.—The method of irrigation by running water in furrows or small temporary ditches made with the plow is a common one in San Joaquin Valley. It is the method generally adopted for the irrigation of fruits, vines, vegetables, hops, or other cultures usually arranged in parallel rows. Water is allowed to flow in furrows, from which it sinks into the soil, being most readily absorbed by the upper layers which have been loosened by plowing. Occasionally drainage is combined with furrow irrigation; more frequently, however, no attention is paid to drainage, the aim being to supply to each furrow only the amount of water that will be absorbed by the soil. The flooding of portions of the ground's surface, as by the furrow methods, compacts the soil, thereby facilitating the return of moisture from below the surface, where it evaporates. To destroy the capillary action of the surface layer, it is necessary to use the hoe or some other implement before it becomes too dry and baked.

Furrow irrigation of cereals.—Cereals are not ordinarily irrigated by the furrow method, but this method of rapidly supplying moisture to a grain field not specially prepared for irrigation has often been resorted to when conditions seemed to justify a special effort to save a parching crop. Sometimes, too, land is wet in the fall of the year, before sowing, by this method.

If the slope of the ground's surface be not too great the furrows, which are generally deep, single plow furrows, are run in the direction of the slope. They are placed 8 to 12 feet apart, according to the porosity of the soil. Water is admitted into them from small ditches, generally crossing them at intervals of 100 to 200 yards. The irrigation commences at the highest part of the field. Water is admitted into a number of furrows at the same time, and the flow is checked or aided in each by an attendant, so as to keep progress uniform and to accomplish a general soaking of the ground's surface. This system of irrigation involves much labor and careful watching. It is relatively expensive. Should the surface of the ground have too great slope, the plow furrows are drawn across the direction of greatest slope on predetermined grade lines. As soon as irrigation is complete the furrows are plowed in, so that they may not interfere with farming operations.

Furrow irrigation of permanent cultures.—The usual method of irrigating trees, vines, or plants set out in rows is to allow water to flow between the rows in plow furrows or small ditches. When rows are far apart, two or more furrows are drawn between rows; ordinarily, however, one deep furrow between each two rows is preferred. The

A. FURROW IRRIGATION OF VINES.

B FURROW IRRIGATION OF ORCHARD

direction of furrows is not always restricted to that of rows of trees, etc., but may be determined by other considerations, such as slope of the ground's surface. Small ditches surrounding individual trees or plants are sometimes connected with the irrigation furrows. It is better to prevent the water from standing around trunks of trees, but no rigid rule can be laid down; the spacing of irrigation furrows is governed by the character of the soil to be irrigated, and is determined for each locality by experience.

Water is usually turned into a number of the irrigation furrows at the same time. At the lower end it may be received into a drain ditch which carries it off for further use. The time required for irrigation from each furrow is somewhat indefinite, but the endeavor is always made not to let water flow longer than may be necessary to give a reasonable supply to the soil. The several furrows are generally less than 300 feet long. Irrigation progresses from highest to lowest portion of the tract to be irrigated. This method of irrigation is in general use without regard to character of soil, but gives particularly good results on comparatively heavy soils which do not absorb water rapidly. When soils are porous and take water from the furrows freely, the furrows are kept shorter than in heavier soils.

Furrow irrigation in level checks.—When, a few years ago, it was feared that the ravages of the phylloxera might extend into the vineyards of Fresno County, it was deemed advisable by some vineyardists to set out all vines in checks which could be completely submerged. Fortunately such submersion, to combat the phylloxera, has never become necessary. But the preparation of the ground for flooding in checks led to a new method of applying water to the land. From a supply ditch, water is admitted into a small ditch upon one side of each check, and from this small ditch it enters deep horizontal furrows which have been drawn between each two rows of vines. As soon as water has filled all the furrows irrigation is complete, and the accumulated water is allowed to sink into the ground. No drainage is combined with this method of applying water.

Furrow irrigation of vegetables.—Where irrigations are to be frequently repeated, as in the case of such products as vegetables, berries, etc., each row of plants is generally set on a ridge a few inches to a foot in height. The length of the rows is varied according to slope of the ground in their direction. The depression between each two rows is utilized as a furrow, which generally receives very little or no fall from end to end. Water is supplied to one end of a set of such parallel depressions, and rises in these to near the height of intervening ridges. It is generally allowed to soak into the ground without drainage.

Irrigation by filling subsoils with water.—The success of farming with irrigation in the Mussel Slough country has attracted particular attention to this method of irrigation. As soon as water was introduced in the canal systems of these very flat lands of the Kings River delta, it

was found that spots quite remote from the canals and ditches became moist, and that it was not necessary, as in other portions of the valley, to apply water to the surface of the ground. This wetting of the lands was attributed to lateral percolation. Soils were supposed to possess some peculiar property which facilitated the transmission of moisture horizontally, and it took a number of years to make clear to the irri-

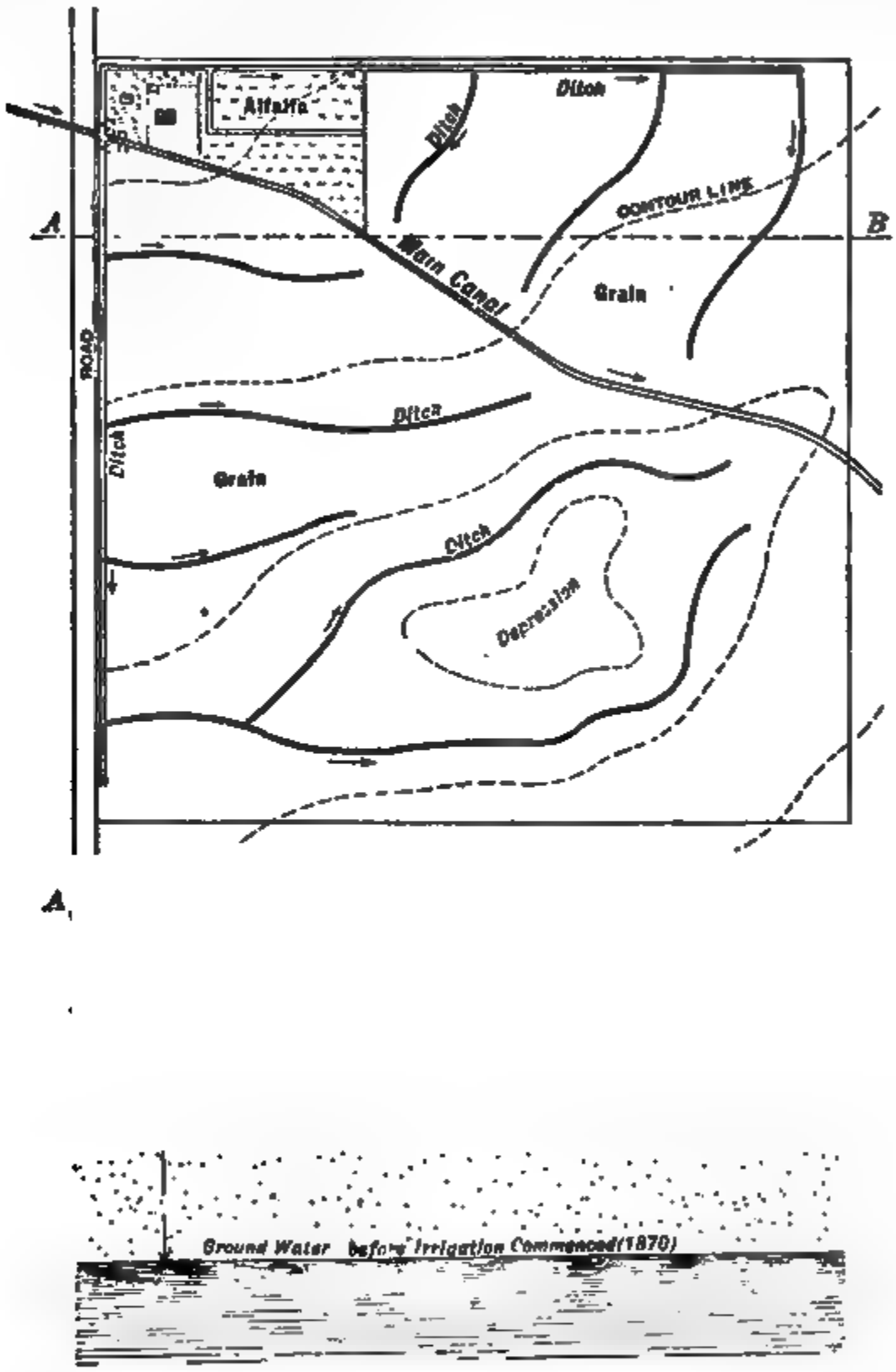


FIG. 5.—Irrigation by filling subsoils with water, Mussel Slough country; map and section.

gators what actually did take place. The soil water of that region before the construction of irrigation canals was at 10 to 18 feet below the surface; now it does not fall below 8 feet. It is kept under control by regulation of the supply in the irrigation ditches and by a natural subsurface drainage, which, as indicated by the slope of the ground-water plane, may be into Tulare Lake.

FURROW IRRIGATION OF GROVE.

This system of irrigation involves but little more than the introduction of water into irrigating ditches in the spring, when the supply is most abundant in river and canals. Irrigating ditches for this purpose are generally constructed about an eighth of a mile apart. They are either permanent or only temporary features of the irrigation system. They receive a very light grade, in order that they may be maintained full, with water flowing sluggishly.

The water sinking from main canals and distributaries and from the irrigating ditches causes a general rise of the ground waters to within 2 or 3 feet of the surface. This occurs late in April or early in May, and as soon as moisture can be detected in the low spots of any field its irrigation for the season is complete.

Careful inquiry in the Kings River delta established the fact that before 1870—that is, before the construction of irrigation works in that section of the valley—the depth to ground water was very generally 15 to 18 feet. It approached to within 10 feet only at a few points nearest the valley trough. It is now kept fluctuating between the limits already indicated, approaching to within 2 to 4 feet of the surface in spring and then settling down to about 8 feet late in the fall.

Irrigation by this method can not be restricted to particular tracts of land; its benefits may extend far beyond any individual tract to be irrigated, and it has frequently happened that lands lying between irrigated farms have derived the full benefit of irrigation without contributing to its cost.

The preparation of land for this method of irrigation is inexpensive, the only necessary cost being the construction of the small ditches. Very little attendance during irrigation is required. Alfalfa lands are sometimes prepared for flooding in order that gophers may be killed, when necessary, by a complete submersion of the cultivated tracts.

The advantages already indicated for this method of irrigation are offset by a decided disadvantage. The rising water brings to the surface alkaline salts, which gradually accumulate and may render unfit for cultivation soils that were originally entirely free from an excess of objectionable salts. Something has been said on this subject in treating of irrigation works in the Mussel Slough country (see page 17).

It remains to be added that the rise of the water table near Fresno has been so pronounced, as a result of the extension of the irrigation systems, that many of the tracts which were originally prepared for irrigation by some other method are now so wet that they are in need of drainage. On many others the application of water to the surface has ceased.

Subirrigation, or irrigation from subsurface conduits.—This method of applying water to land has not been so satisfactory as was hoped, but, having been introduced in some localities on a large scale, it should not be passed without notice.

The intent of this method of irrigation is to supply a moderate quantity of water directly to those parts of the soil where moisture is needed without wetting the surface of the ground. Thereby it was hoped to economize water, to greatly simplify its control and distribution, to cheapen irrigation, and to avoid baking of soil and the necessity of breaking up its surface after each application of water.

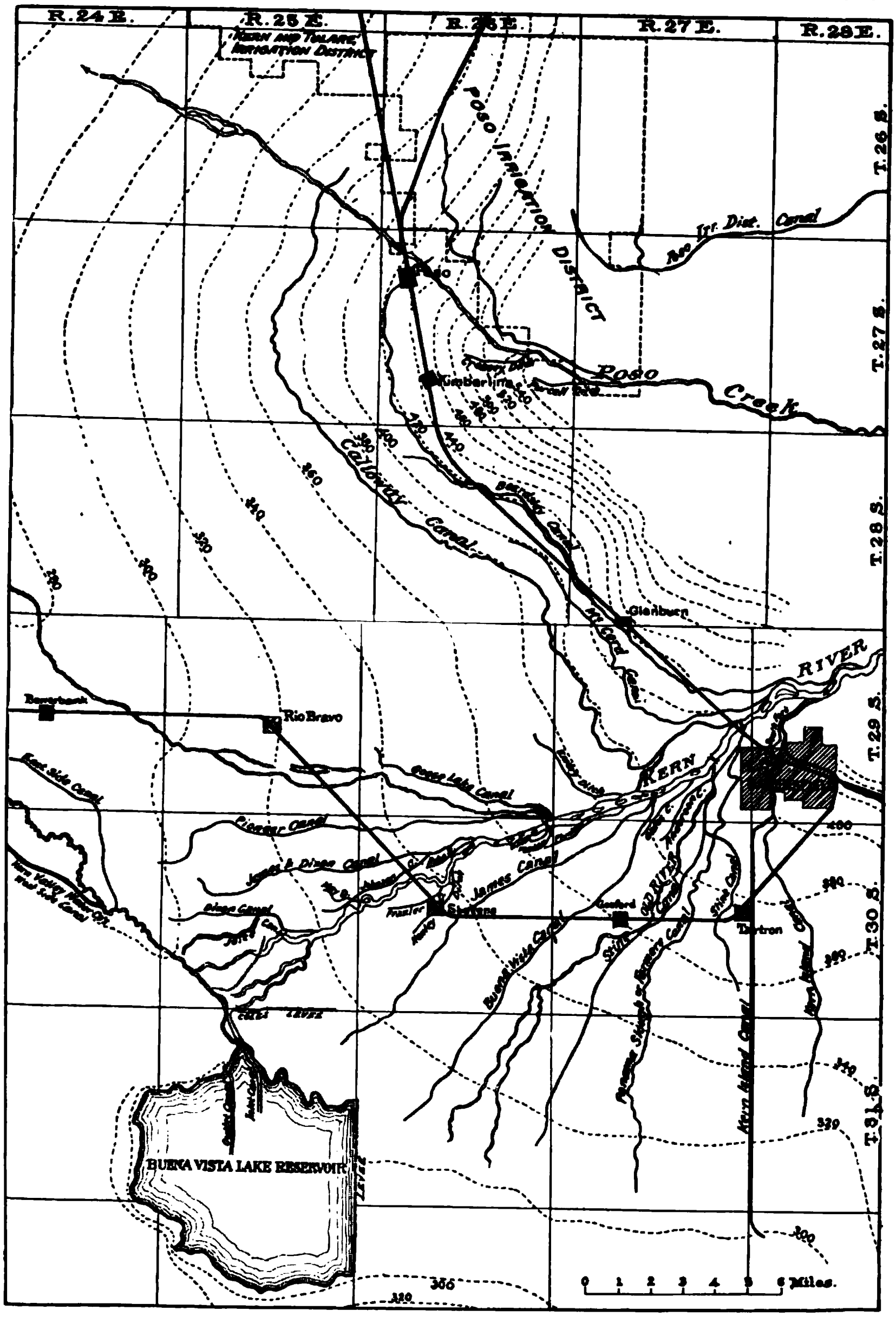
Water is distributed to all parts of the land to be irrigated in cement pipes, from which it escapes through perforated plugs of wood. It is admitted into these pipes under a low pressure, sufficient to insure the escape of some water even in the highest parts of the land to be irrigated. The system is applicable only to smooth-surfaced tracts having but slight slope.

The final distributing pipes are constructed by a peculiar machine. They are made in place and are continuous. The diameter of their bore is 2 inches. At intervals, corresponding to the distance between trees or vines, they are perforated from above, and a wooden plug with a hole about one-sixteenth inch in diameter, lengthwise through it, is inserted in the perforation. This plug is protected by means of a hollow cap, or earth guard, resting loosely upon the pipe over it. The pipe is placed 20 inches or more below the surface of the ground, so as not to interfere with plowing, cultivation, etc. Water is conducted to the 2-inch pipes—which may be laid between each two rows if the rows be far apart, as in the case of trees, or between alternate rows if they be close together, as in the case of vines—by means of a system of 6-inch and 4-inch pipes, which in turn receive water from a main supply pipe, generally about 8 inches in diameter. At all points where the 8-inch and 6-inch pipes branch, vertical cylinders, opened at the top—so-called hydrants—are introduced, by means of which the water may be shut off from one line or the other of pipe. This is accomplished by holding the inlet pipe higher in the cylinder than the outgoing pipe, and providing a seat for a disk to be inserted between the two.

When water is being supplied to any part of a vineyard or orchard, it will escape through the plugs into the ground, and its quantity must be sufficient to keep the stand in the hydrants everywhere above the highest parts of the 2-inch pipe system, so that there may be no doubt that water is escaping from every plug in the tract under irrigation.

Under favorable conditions it will cost about $50 per acre to prepare ground for irrigation by this method. The roots of trees and plants will, notwithstanding every precaution to prevent it, find their way into the lines of pipes at exposed points, and may in time seriously interfere with their successful use.

Until irrigators are required to be very much more economical in the use of water for irrigation than at present, the matter of expense alone will interfere with any extended use of this system of irrigation.



KERN RIVER DELTA.

KERN RIVER.

HYDROGRAPHY.

Kern River is the most southerly of the large streams descending from the slopes of the Sierra Nevada into San Joaquin Valley. It breaks through an outlying spur of the main range in a deep, rocky gorge, which terminates abruptly about 10 miles east of Bakersfield. For a distance of 18 miles from the canyon mouth the river flows westerly between high, gravelly bluffs, in which the adjacent rolling lands and mesas terminate. Occasional low, level tracts border it. From between the flanking hills and uplands the river emerges upon the plains of San Joaquin Valley just northeast of Bakersfield. Thence the main stream has a southwesterly course, flowing in a shallow bed 300 to 800 feet wide nearly 20 miles, to a point within a few miles of the trough of the valley; thence southerly into Buena Vista Lake, now used as a reservoir for irrigation purposes.

Year after year the sandy material eroded by the river from its mountain watershed has been deposited in San Joaquin Valley below the point at which the river emerges upon the plain. New channels have been constantly forming while old ones were being obliterated, and the delta region thus built up extends 20 to 25 miles toward the south and west, terminating in a great semicircle formed by Kern and Buena Vista lakes and the upper portion of Buena Vista Swamp. The central portion of this delta is generally referred to as Kern Island. The flow of water in many of the delta channels is now under control, and they are classed as canals.

Principal among these delta channels are: South Fork, or Old South Fork, which has a southerly course from its head, about 2 miles northeast of Bakersfield, to its outfall into Kern Lake; Old River, which has a southwesterly course from its head, about a mile and a half west of Bakersfield, toward a point between Kern and Buena Vista lakes; and Buena Vista Canal Slough, also flowing southwesterly, which leaves the new channel of Kern River about 2 miles below the head of Old River. Of these channels South Fork was the main channel of the river until 1862. Old River then became the main water way, and remained so until New River was formed by the freshets of 1867–68.

Kern River enters San Joaquin Valley with a total mountain drainage area of 2,345 square miles. By far the greatest portion of the region drained lies in the high Sierra Nevada. Precipitation in the highest portions of the river's drainage basin is generally in the form of snow. But an occasional heavy rain falling on large deposits of snow causes great freshets, generally early in the spring. Ordinarily the river is at a low stage from September to January, inclusive. It is at a high stage from April to July, and at a medium stage in February and March, and in August.

The discharge of the river has been estimated by the State engineering department for the six years 1878 to 1884. According to the results of this estimate, which is based on many measurements and an imperfect record of rise and fall of the river, the average amount of water supplied by Kern River was about 430 second-feet for the months November to January (inclusive); 800 second-feet for February to April;. 2,450 second-feet for May to July; and 570 second-feet for August to October. The average annual flow of the river for that period was rated at 1,110 second-feet.[1] The discharge of the river as here noted refers to the State engineering department gaging station,

FIG. 6.—Discharge of Kern River, California, 1894–95.

about 3 miles below the point where the river breaks from its mountain gorge and enters upon its course across porous alluvial deposits.

Measurements made by Mr. A. K. Warren, under the direction of Mr. Walter James, chief engineer of the Kern County Land Company, show the facts indicated in the following table and accompanying diagram in regard to the discharge of Kern River for the four years from 1894 to 1897.[2]

[1] See Physical Data and Statistics of California, collected and compiled by the State Engineering Department of California, Sacramento, 1886, pp. 410, 470–472, 476–477.

[2] Bull. U. S Geol. Survey No. 140, 1896, pp. 267 274. For further information concerning the flow of Kern River see Twelfth Ann. Rept. U. S. Geol. Survey, Part II, 1891, p. 319, Pl. LXXX; Bull. U. S. Geol. Survey No. 131, 1896, p. 79; Eighteenth Ann. Rept. U. S. Geol. Survey, Part IV, 1897, p. 395.

Estimated monthly discharge of Kern River at Bakersfield, California.

[Drainage area, 2,345 square miles.]

Month.	Discharge.			Total.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth.	Per square mile.
1893.	*Second-feet.*	*Second-feet.*	*Sec.-feet.*	*Acre-feet.*	*Inches.*	*Sec.-feet.*
October	554	517	534	32,861	0.26	0.23
November	559	467	518	30,827	.24	.22
December	590	430	516	31,757	.25	.22
1894.						
January	741	762	661	40,644	.32	.28
February	1,114	604	717	39,817	.32	.30
March	1,443	762	1,001	61,541	.65	.43
April	1,892	1,209	1,495	88,952	.71	.64
May	2,208	1,228	1,607	98,798	.79	.69
June	1,719	871	1,085	64,557	.51	.46
July	1,051	400	700	43,036	.34	.30
August	549	256	335	20,565	.16	.14
September	382	172	248	14,756	.12	.11
October	363	224	279	17,178	.14	.12
November	268	230	244	14,500	.11	.10
December	805	234	470	28,908	.23	.20
Per annum	2,208	172	737	533,252	4.40	.31
1895.						
January	1,616	473	809	49,762	.40	.34
February	4,762	675	1,252	69,536	.55	.53
March	3,004	987	1,374	84,437	.67	.59
April	3,897	1,911	2,724	162,076	1.29	1.16
May	5,384	3,100	4,369	268,608	2.14	1.86
June	3,721	2,174	2,906	172,919	1.37	1.24
July	2,063	867	1,482	91,113	.73	.63
August	1,073	354	629	38,665	.31	.27
September	676	290	344	20,469	.17	.15
October	612	276	327	20,106	.16	.14
November	436	308	346	20 588	.17	9.15
December	447	368	403	24,779	.20	.17
Per annum	5,384	276	1,413	1,023,058	8.16	.60
1896.						
January	3,101	377	747	45,931	.37	.32
February	798	559	617	35,489	.28	.26
March	2,089	652	951	58,475	.47	.41
April	1,262	766	972	57,838	.46	.41
May	3,370	934	1,401	86,144	.69	.60
June	3,611	1,244	2,476	146,142	1.17	1.05
July	2,210	741	1,346	82,762	.66	.57
August	741	353	486	29,883	.24	.21
September	473	234	304	18,089	.14	.13
October	425	223	267	16,417	.13	.11
November	416	288	355	21,124	.17	.15
December	426	313	347	21,336	.17	.15
Per annum	3,611	223	854	619,630	4.95	.36
1897.						
January	832	350	373	22,935	.18	.16
February	2,306	516	809	44,930	.36	.35
March	2,044	688	923	56,753	.45	.39
April	4,410	1,094	2,914	173,395	1.38	1.24
May	5,342	4,054	4,580	281,613	2.25	1.95
June	4,352	1,289	2,308	137,395	1.09	.98
July	1,536	644	1,006	61,857	.49	.43
August	671	338	469	28,838	.23	.20
September	363	260	295	17,554	.14	.13
October	441	278	340	20,906	.17	.15
November	447	289	355	21,124	.17	.15
December	1,023	327	422	25,948	.21	.18
Per annum	5,342	260	1,234	893,248	7.12	.53

1894. Maximum discharge, May, 2,208 second-feet; minimum discharge, September, 172 second-feet; average for the year, 737 second-feet.

1895. Maximum, May, 5,384 second-feet; minimum, October, 276 second-feet; average for the year, 1,413 second-feet.

1896. Maximum, June, 3,611 second-feet; minimum, October, 223 second-feet; average for the year, 854 second-feet.

1897. Maximum, May, 5,342 second-feet; minimum, September, 260 second-feet; average for the year, 1,234 second-feet.

The gaging station of the State engineering department was located on the Rio Bravo Ranch, about 3 miles below the termination of the river's granite canyon, a short distance below the point where in 1879 the material of which the river bed was composed changed in character from bowlders and cobbles to gravel and sand. The several measurements made subsequent to that time, and until the close of the work of the State engineering department, showed a gradual erosion of the river bed, resulting in a downstream movement of the upper end of the gravel and sand bars, which led to inquiry concerning conditions in preceding years and to the conlusions that a few years subsequent to the great freshet of 1861–62 the sand and gravel bars were at a much higher level than in 1879; that erosion had continued from year to year, though at a somewhat irregular rate, until 1884 and was then still in progress; that the aggregate erosion during the five years covered by observations was 5.3 feet, and that at some time preceding the freshet of 1861–62 the river had for a long period occupied a bed fully as low as that of 1883. A row of trees planted at the water's edge at a mean stage of the river about 1868, and now well above the reach of the water, has been pointed to as evidence of a former higher position of the river bed. On the other hand, deep, well-worn depressions made by the Indians in grinding food materials in the tops of great granite bowlders, barely projecting above the low-water stage of the river in 1883, gave evidence of a preceding protracted low position of the river bed. It seems reasonable to expect, therefore, that other great freshets may again temporarily fill the river bed with sand and gravel, and that in years of ordinary flow, such as the entire series of seasons since 1867–68, the river will have a tendency to continue its erosive action.

Due allowance for the changes in actual elevation of the river bottom were, of course, made in interpreting results at the gaging station.

The original course of Kern River waters, westerly and southerly across its delta, widely dispersed in numerous channels, has by natural agencies, aided by the operations of man, been modified to the extent that now at high stages all water in excess of the capacity of the irrigating ditches and canals is kept under reasonable control in one main channel having a direct southwesterly course toward Buena Vista Lake.

Buena Vista Lake has been shut off at the east from its connection with Kern Lake by means of a high levee, which has a north-south course, following the line between Rs. 25 and 26 E. for a distance of over 5 miles.

A. KERN RIVER, LOOKING DOWNSTREAM FROM CANYON

B. KERN RIVER, TWO MILES BELOW CANYON LOOKING UPSTREAM.

Thus Kern River water is prevented from reaching Kern Lake, the bed of which is now dry, arable land, and Buena Vista Lake is converted into a large reservoir, the capacity of which is said to be about 150,000 acre-feet. From the northwestern margin of Buena Vista Lake an outlet canal leads into Buena Vista Slough and thence to canals proper of the Kern Valley Water Company, of which the westernmost one, located near the western margin of Buena Vista Swamp, has been planned large enough to afford passage for the outflow waters from the lake when the reservoir is full and the river is high. This canal, therefore, for a long distance takes the place of Buena Vista Swamp, which was the original water way, conducting the outflow from Buena Vista Lake into Tulare Lake. The three lakes which have been or are the recipients of water from Kern River are very flat depressions, without well-defined banks. The beds of Kern and Buena Vista lakes are at an elevation of about 285 feet above sea level; the bed of Tulare Lake is at an elevation of about 175 feet. The area covered by Kern and Buena Vista lakes combined (before the spread of water was restricted artificially) was about 80 square miles when the lakes were full, at which stage the maximum depth of water in either did not probably exceed 14 feet. The area of Tulare Lake fluctuates between 195 and 760 square miles, but the lake water has not spread to the extreme limit of the full lake since 1868.

The lands of the east side of the San Joaquin Valley plain, commanded by the Kern River canals, are very smooth surfaced. Those of the river delta slope uniformly toward the west and south at the rate of 6 to 7 feet to the mile. The only surface inequalities on Kern Island are due to the land-building tendency of the river, which has left broad, low ridges of sand to mark the alignment of channels of former epochs in its history. On the north side of Kern River the delta lands merge almost imperceptibly into the granitic sandy lands of the general valley plain, and the gentle westerly slope from the base of the foothills of the Sierra Nevada is almost unbroken to Buena Vista Swamp.

SOILS AND RAINFALL.

Near the base of the foothill belt, northward as well as southward from the river, the soil is a coarse granitic sandy loam, showing an occasional growth of cactus, and rather forbidding in appearance, yet very productive with water. To the southeast of Kern Lake a large area of fine sandy loam, known as the Weed Patch, marks the sink of Caliente Creek. The soils of the eastern portion of Kern River delta are generally loams, ranging from those rich in clay to soils of a peaty character and to soils of almost pure sand. Different kinds of soil are here frequently found close together, and it is often remarked that probably no single square mile of land could be found whose soil would

not have to be put into several classes. Toward the south and west on Kern Island the soil becomes heavier, and near the high-water line of the lakes it is strongly impregnated with alkali. It has a peaty character in the swamp-land areas adjacent to the lakes, also northwestward from Buena Vista Lake throughout the broad tract known as Buena Vista Swamp, which extends about 40 miles northwesterly toward Tulare Lake. These swamp lands were originally covered with a dense growth of reeds—"tules." Their soil is generally a light black vegetable loam or mold, underlain by a dark-colored clay. Eastward from these swamp lands, which mark the trough of San Joaquin Valley, is a long parallel strip of alkali land of inferior quality, which lies to the west of a narrow strip of fertile land flanking the Goose Lake Slough channel. Farther eastward are the sandy loams and coarse granitic soils of the main east-side plain. These generally have a substratum of dry, fine yellow clay, sometimes of sufficient hardness to be called hardpan. This is usually found at a depth of 3 or 4 feet.

The southern or upper end of San Joaquin Valley, in which lie the lands commanded by the Kern River waters, is a region of very light rainfall. The annual average fall is about 5 inches. Profitable cultivation of the soil without the aid of other water to supplement the scant rainfall is not possible.

Kern River water is used to a small extent for irrigation in the valley of South Fork far up in the mountains, also for the irrigation of relatively small areas of bank and mesa lands within the foothill section of the river's course; but the region of principal use is the river delta and a broad expanse of country extending far northward from the river and lying below the base line of the foothills.

CANALS AND DITCHES.

Rio Bravo Ranch canals.—Kern River crosses the foothill belt in a valley, generally one-half mile to a mile in width, with occasional strips of bottom land on one bank or the other. These are frequently backed by higher terraces or mesas with rich, black loamy soil, beyond which the hills rise in irregular disconnected ranges. The Rio Bravo Ranch lies just below the point where the river breaks out of its canyon. Several small ditches have here been built for local irrigation. A waterwheel was first made use of. It was constructed in 1879 by Mr. John Barker, and was intended to lift water 28 feet. The wheel is reported to have delivered the quantity of water expected, but the land required more than was anticipated; consequently the wheel was soon abandoned as a source of supply, and a direct diversion into a ditch constructed along the base of a high bluff on the south side of the river was resorted to. The river, however, for a series of years was there deepening its channel, rendering necessary frequent extensions of the head of the ditch upstream, and making ditch maintenance expensive. Its cost has probably been somewhat in excess of $3,000.

A HEAD OF KERN ISLAND CANAL LOOKING UPSTREAM

B. HEAD OF KERN ISLAND CANAL, LOOKING DOWNSTREAM.

To irrigate lands on the north side of Kern River, in the same locality, the Pierce & Barker Ditch has been constructed. It came into use several years after the Barker Ditch on the south side of the river. This ditch lies at the base of the north-side hills, and for some distance is cut into an almost vertical bluff. There is also a "Pierce & Barker" ditch on the south side of Kern River, but its source of supply is Cottonwood Creek, a tributary of the river, from which diversion is made near its confluence with the main stream. This ditch has a length of 4½ miles. It was constructed in 1885. All of these ditches are small and for private use only.

Another small ditch just below the Rio Bravo Ranch on the north side of the river is the Barker & Wilson Ditch, constructed about 1884, which commands a narrow strip of land along the northern bank of the stream.

The principal crop cultivated by irrigation from these ditches in the foothill section of the river is alfalfa.

Kern Island Canal.—As early as 1864, when there were but a few white families in the vicinity of Bakersfield, Colonel Baker constructed a levee northeasterly from the present town site and placed a gate in the delta channel known as South Fork, at the point where this channel was crossed by the river levee. Subsequent freshets filled the approaches to Panama Slough and to South Fork with sand, and the river cut out a new channel farther to the north and west. The settlers who had already become dependent upon the older water courses as sources of water supply for irrigation and for stock, at once made organized efforts to reopen the head of South Fork, but with indifferent success.

In 1869 Messrs. H. P. Livermore and Julius Chester, having determined that an artificial channel was necessary to replace the upper portion of South Fork, constructed a ditch 25 feet wide, the head of which was a short distance above the present head gate of the Kern Island Canal. This ditch was carried along the base of the hills on the south bank of Kern River and terminated in South Fork a short distance below its original head.

At the same time a number of Mexican settlers made a diversion of water from South Fork in a southerly direction, commencing at a point about a mile below the head of that channel. The ditch constructed by them is known as the "Arujo" Ditch, and its lower portion is still in use as a branch of the Kern Island Canal. This small ditch seems to have suggested the idea of the Kern Island Canal, for the construction of which a company was organized in 1870. It was proposed to unite in one system the entire delta area of the river known as Kern Island, as well as a broad belt of higher land lying to the east of the delta. A combination was effected with the owners of the swamp lands of this region, which had recently been sold by the State, conditioned upon reclamation, whereby the new canal company became

the successor in interest of the reclamation district that had already been formed. The canal company was therefore formed with the avowed purpose of protecting from overflow and of supplying with water for agricultural, domestic, and manufacturing purposes a territory of about 120,000 acres. The Kern Island Canal Company acquired the ditch and water rights of Messrs. Livermore and Chester, as well as some of the other private rights vested or supposed to be vested in some of the settlers on South Fork. The construction of the "Mill" section of the Kern Island Canal was at once commenced, and extended southward about 2 miles, part of the distance following the alignment of the Arujo Ditch. Above this section of the canal the South Fork channel was enlarged, and some systematic effort was made to keep up the supply of water from the river. For the settlers on South Fork, who had not transferred their rights to the canal company, water was turned down that channel free of expense. About 1877 the upper portion of the South Fork channel was entirely abandoned, being replaced by a canal at higher level—an extension of the Livermore-Chester Ditch, located between the old water way and the base of the bluff south of the river. This new canal section was extended to the head of the "Mill" section, where water was dropped about 6 feet to the original level of that canal branch. Meanwhile the various branches of the Kern Island Canal had been extended southward as demand for water increased, and had reached the vicinity of Kern Lake. In 1875 the Kern Island Canal Company was granted franchises for the distribution of water in Bakersfield, where actual delivery of water through its ditch system commenced in May, 1875.

At the time of the formation of the Kern Island Canal Company the swamp lands to be protected by it against inundation were already considered safe, their reclamation in the sense of preventing overflow being regarded as complete. It was claimed, however, that the State had no right to appropriate the money to the credit of this land in the swamp-land fund to any other purpose than its reclamation, and that reclamation should be construed to mean the making of the land productive. The canal company therefore demanded and received from the State the money to the credit of the lands in question as a contribution toward the cost of the irrigation system. The amount of money thus contributed by the State was between $12,000 and $14,000.

The method of constructing the main branch of the Kern Island Canal, which extends from a point on South Fork about a mile south of Bakersfield southerly to Kern Lake, is not without interest. A 5-foot plow drawn by 40 yoke of oxen was used in breaking ground for this canal. The loosened earth was then spread to right and left by means of a V-shaped scraper, also of monstrous proportions, being some 30 feet long and 12 to 15 feet wide. As soon as sufficient water way was thus created to afford some erosive effect, water was turned into the partial excavation and it rapidly cut out an ample water way.

A. KERN ISLAND CANAL REGULATOR AND WASTE GATE, LOOKING UPSTREAM.

B. KERN ISLAND CANAL REGULATOR AND WASTE GATE, LOOKING ACROSS THE CANAL.

The excessive grade, 6 to 7 feet to the mile, of the finished canal soon caused the erosion to extend beyond desirable limits and threatened disastrous results by persistent encroachment on the canal banks. It therefore became necessary to reduce the gradient of the canal by means of check weirs or drops (as shown in Pl. X, *A*), which were placed one-half mile apart. These check weirs were constructed according to designs proposed by Mr. F. H. Colton, at that time superintendent in charge of the canal, and although very simple in arrangement, they proved to be efficient and satisfactory. Weir boards, generally of 1 inch material, were supported by inclined rafters, usually 4 by 6 inches. The rafters were placed at such angle, preferably flatter than 45°, as would best fit the spacing of the vertical posts supporting the sides of the weir box. The rafters transmitted water pressure by means of inclined supports, 4 inches square, to the floor timbers. The rafters were toed into the sill at the upper edge of the floor of the weir box. The floor itself was constructed of 1-inch material nailed to sills of 4 by 6 inch timber, 4 feet apart, which in turn rested upon mud sills, also about 4 feet apart. The floor of the weir box was placed 1½ feet below the downstream-grade height of the canal bottom, and light sheeting was driven along the upper and lower edges of the floor to depths varying, according to character of soil, from 1½ to 4 feet. Wings were carried into the canal banks at right angles to the direction of the canal. They were supported in part by upright posts, in part by timbers across the top of the structure, which at both ends were allowed to project well into the bank. The length of the wings varied according to depth of canal. Weir boards were permanently nailed to the rafters to the height of the grade of canal bottom above the structure. All other weir boards were loose and could readily be moved by hand. Spaces between rafters were usually 4 feet. A plank across the structure, supported by the ends of the rafters, made a convenient footbridge and afforded access to the several sections of the weir. The cost of these check weirs on the Kern Island Canal is reported to have been about $200 each.

The canal head gate is constructed on substantially the same plan. It has a clear width of 48 feet. A waste gate has been placed in the right bank of the canal just above the head gate.

The diversion of water from the river into the canal is accomplished by an inexpensive extension of the right-bank canal levee upstream for nearly half a mile, and its projection in the form of a very low sand-and-brush dam diagonally across the southern portion of the very flat, sandy river bed.

The aggregate cost of the Kern Island canal system has been about $[illegible]0,000.

The canal has a right to 300 second-feet of water, conceded to it by riparian owners, and taking precedence over all other diversions. Its capacity is reported to be 500 second-feet.

Old South Fork.—The delta stream of Kern River known as South Fork supplied water to a few settlers some years before the construction of the Kern Island Canal was thought of. When Colonel Baker, in 1864, undertook the construction of a levee for protection against overflow, a gate was put into the South Fork channel for the control of its flow of water. The freshets of 1867–68, which produced marked changes in the character and alignment of the main channel of Kern River, filled the head of South Fork with sand. Organized effort was necessary to reestablish a connection of the upper end of the South Fork channel with the river. It is reported that from thirty to forty persons contributed time and labor to this work, the result of which was not, however, entirely satisfactory. The river channel had been deepened; the new cut to the river was nearly half a mile below the original head of South Fork, and great difficulty was experienced in

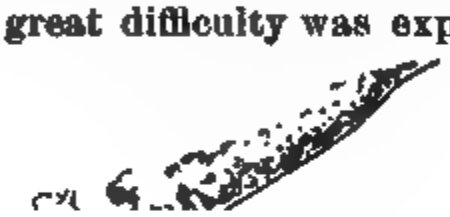


FIG. 7.—Head of Kern Island Canal.

maintaining an artificial barrier at the head of the new channel to turn river water into it. This difficulty led to the construction of the Livermore-Chester Ditch, as already explained, and for a number of years the supply of water to South Fork was through this ditch. About 1877 the use of the upper portions of South Fork was abandoned by the Kern Island Canal Company, and the delivery of water by this company to the irrigators from South Fork ceased. The users of water from South Fork and from Panama Slough resumed control of its head works, and have since maintained this channel as an independent irrigation ditch. A new connection with the river was established near the original head of South Fork, and with more or less trouble it has been kept in efficient service. The management was almost without system, and corporate organization of the owners was not effected until 1885.

A CHECK WEIR OR DROP ON KERN ISLAND CANAL

B. KERN RIVER AT HEAD OF SOUTH FORK

Through the upper portion of South Fork water can be supplied to the lower levels of the Kern Island Canal; Panama Slough is fed with water from South Fork, and as the lower portion of Panama Slough is used as a water way by the Farmers' Canal, there is such interdependence between these several canals, complicated by the fact that many irrigators hold rights to water from two or more of them, that segregation of areas dependent upon any one of them is out of the question.

The principal distributaries of South Fork water are the Jewett Ditch, the Cotton Ranch Ditch, and smaller ditches of landowners in the immediate vicinity of Bakersfield. The capacity of South Fork is generally stated at 50 to 75 second-feet, and the amount annually expended for maintenance is about $1,250. The first cost of the irrigation works can be stated only approximately. It is likely that $3,000 to $4,000 have been expended on construction work.

Farmers Canal.—In 1873 a canal about 50 feet wide and 3 feet deep was excavated from a point on the south bank of Kern River just above the Southern Pacific Railroad, in a southeasterly direction, to a connection with a natural channel known as Cotton Ranch Slough or Skyles Slough. This canal is known as the Farmers Canal. Its water, delivered into Cotton Ranch Slough, flows therein 1½ miles to Panama Slough, and is distributed by a number of small branch ditches throughout the central and southern portions of Kern Island. The canal proper is only about a mile in length. It has recently become of considerable importance as a source of supply for the Stine and Anderson canals, which formerly received their full supply directly from Kern River at the head of Old River, about 3 miles west of Bakersfield.

In 1880 Messrs. Celsus Brower and Walter James estimated the total cost of construction of this canal and its branches at $18,800.

Panama Slough.—Panama Slough hardly deserves separate enumeration among the irrigation works from Kern River, because it is now supplied with water through the head of South Fork. It was, however, in use as an independent source of supply before permanent connection between it and the South Fork channel was established by the freshets of 1867–68. Irrigators dependent upon the flow of water in Panama Slough united with those on South Fork in 1868, when it became necessary to reestablish a connection of these streams with the main channel of the river. All of that portion of Panama Slough below Bakersfield is used jointly by the irrigators who depend upon the Farmers Canal for their supply and by those who hold rights as original users of water from the slough itself.

The principal distributary of the Panama Slough water is the Panama Ditch, the cost of which Mr. Celsus Brower in 1880 reported as having probably exceeded $6,000. The main distributing ditch and branches were then reported to have an aggregate length of 8 miles. Its width was given as 10 feet and its depth of channel as 2 feet.

Castro Ditch.—A comparatively unimportant irrigation ditch which for many years diverted water from the south banks of Kern River at the head of Old River is known as the "Castro" or "Mexican" Ditch. It is reported to have been in use as early as 1859, at that time supplying water to the lands of a few Mexican settlers. This ditch is about 16 feet wide, 2 feet deep at its head, and about 5 miles long. Its capacity is generally rated at about 15 to 20 second-feet, and there may have been expended upon it from $2,000 to $3,000. The head works of the canal, or rather the point of diversion from the river, has within the last few years been extended upstream about a quarter of a mile from the original intake.

Fisher & Abley Ditch.—About 1869 a small ditch known as the Fisher & Abley Ditch was constructed, paralleling the Castro Ditch, and delivering water into Reeder Slough, thence into Panama Slough, from which it was again diverted, a few miles below, for use upon several small farms. That portion of the ditch above Reeder Slough has been abandoned and the lower portion has become dependent upon the Farmers Canal for its supply of water.

Stine Canal.—This name has been applied to portions of Old River and several distributing canals since 1873. In that year the settlers along this river channel united in the construction of a weir about 175 feet long across the head of Old River, and two main branches of the canal were subsequently diverted from this stream. The first one of these, in order downstream, is known as the Call Branch, or Branch No. 1. It has its head about three-quarters of a mile below the head of Old River, is 20 feet wide for about a mile, then 30 feet wide, gradually contracting again to 25 feet. The original depth was intended to be 3 feet, but the channel was made somewhat deeper. One of its branches connects with a branch of the Kern Island Canal. Branch No. 2 of the Stine Canal is diverted from Old River about 5 miles below its head. It is about 6 miles long. The diversion of water from the channel of Old River into these branches is accomplished by means of weirs or regulating gates that serve to control water elevation.

The water passing the head of Branch No. 2 flows on toward the lakes and is occasionally used for wild flooding of grass lands. Recently the diversion of water for the Stine Canal was made through the head of the Farmers Canal and delivered to the former through a canal section called the extension of the Stine and Anderson canals. The capacity of the Stine Canal is claimed to be about 200 second-feet.

The cost of the works, including repairs, was estimated for the principal owners in 1880 at $87,000. This does not include the extension to the Farmers Canal, which was made subsequent to that time.

Anderson Canal.—This canal, which is also called the "Baker & Noble Canal," was constructed, in part, at least, in 1872. The diversion of water for it was originally made from the south bank of New Kern River, about one-quarter of a mile below the head of Old River; but as

ownership of a number of canals became centered in the same group of owners, it was thought desirable to establish common head works for this canal together with the Stine and Castro canals, at the head of Old River. It was therefore extended to this point, and for many years one system of works served to divert water for all three of these canals. Within the last few years a further consolidation of canal head works has been effected, and the water for the Stine and Anderson canals is now diverted from the river through the upper section of the Farmers' Canal, as already explained. The Bellevue property, one of the many possessions of the Kern County Land Company (J. B. Haggin, principal owner), is the locality where the water of the Anderson Canal is used.

Gates Canal.—This canal is reported to have been constructed in 1872 and 1873. It was enlarged in 1874 from a bed width of 9 feet to 12 feet. Its water is used only on the Bellevue Ranch. Its diversion is made about three-quarters of a mile below the head of Old River. It is only 2 to 3 miles long, and its capacity is 30 to 40 second-feet.

Buena Vista Canal.—This name has been given to one of the delta channels of Kern River, together with its system of distributary ditches. The natural water course referred to broke out from the south bank of Kern River about 2 miles below Old River. It was provided with a head gate 26 feet wide in 1870, and a new connection with the river was established. For some years thereafter the settlers along this slough, which had a southerly course, and along its main branch, Button Willow Slough, made use of the water thus admitted under control, for irrigation purposes. Diversion from the sloughs was effected by means of temporary brush dams. In 1875 the canal proper was constructed. The slough was permanently closed about a mile below its head, and its lower section was replaced by the artificial channel of Buena Vista Canal. The capacity of the canal is probably between 100 and 150 second-feet. The cost of works and repairs to 1880 was estimated for the owners by Mr. W. R. Macmurdo at $26,000. A weir of the ordinary light flashboard type is maintained in Kern River just below the head of the James Canal to force water into the Buena Vista and James canals.

James Canal.—This canal was constructed for the irrigation of the odd-numbered sections of land westward from Old Kern River on Kern Island. The construction work commenced late in 1871. The diversion of water from the river is made a few rods below the head of Buena Vista Slough. As originally constructed the canal was 100 feet wide for about 1,000 feet, thence 20 feet wide for a distance of 300 to 400 feet, and 30 to 40 feet wide throughout the rest of the first three-quarters of a mile of its course. Its fall in this distance is 2 feet, and it is intended to carry water 3 feet deep. The length of the main canal is about 18 miles, but its lower portions have fallen into disuse on account of the abandonment of Lake Ranch, where an unsuccessful attempt was

made to irrigate strongly alkaline land. Mr. W. R. Macmurdo, about 1879, estimated the total expenditure on the canal at $16,000. The river weir at the head of the James Canal serves to force water into this canal as well as into the Buena Vista Canal. It is in type similar to the Pioneer weir.

Plunkett Ditch.—This ditch was constructed in 1873. It diverted water for the river about three-quarters of a mile below the head of Buena Vista Slough, and had a southwesterly course. It was made 12 feet wide and 2 to 2½ feet deep, and its length was about 4 miles. Some years later a connection with the James Canal was established, and the Plunkett Ditch may now be regarded as a branch of the larger canal.

Meacham Canal.—The Meacham Canal is one of the small ditches taking water from the south side of Kern River just above the Pioneer Bridge, about 6½ miles west of Bakersfield and about 5½ miles below the head of Old River. It was constructed in 1873. Its length was only 3 to 4 miles and its width 8 to 10 feet. The depth of water to be carried was 2 to 3 feet. The canal is now arranged to deliver its water into the James Canal, with which it has been connected.

Wilson Canal.—The head of this ditch, which was constructed in 1874, was originally located about one-quarter of a mile below the Pioneer Bridge, but in 1875 the ditch was extended upstream to a point alongside the head of the Meacham Canal, just above the bridge. The ditch is only 1 to 2 miles long, about 5 feet wide, and 2½ feet deep.

Henley and Frazier ditches.—These are two small diversions from the south side of the river, about 4 miles below the Pioneer Bridge. The former was constructed in 1874, the latter in 1873. Each is about 2 miles long. Their combined capacity was probably less than 20 second-feet. No information is available as to whether they are still in use.

Beardsley Canal.—The head of Beardsley Canal is about 1½ miles above the head works of Kern Island Canal, on the north side of Kern River. It is the uppermost of the Kern River canals which divert water from this river for the irrigation of portions of the main east-side plain of San Joaquin Valley. The construction of the canal extended through several years, commencing late in 1873. Its course for about 100 feet near its head is along the base of an almost vertical bluff of cemented gravel, and about 2 miles below its head it lies in an extensive cut, 8 or 9 feet deep, through a second bank of cemented gravel. This cut is nearly half a mile long. Otherwise the canal is located on ground favorable for canal construction. The canal was planned to follow a grade line skirting the southwestern base line of the Sierra Nevada foothills, and in this respect differed materially from the works on the other side of the river, which, except the upper section of the Kern Island Canal, were all constructed in the direction of the greatest fall of the land, thus occupying positions which are usually assigned to laterals. The Beardsley Canal was originally made 15 feet

wide and 2 to 2½ feet deep, but owing to the light grade on which it was constructed—0.8-foot fall per mile—it was found difficult to keep it reasonably free from obstruction by the rapidly growing vegetation, and it became necessary to enlarge the canal to make its fall more effective. A timber weir of the open flashboard type is maintained across the river at the head of Beardsley Canal. For many years the full length of this canal was about 8 miles, but as it, with the majority of the other Kern River canals, came into possession or under control of the same owners, the Kern County Land Company, it was extended northward to and across Poso Creek, and now has a total length of about 25 miles. Its laterals frequently extend westward to a connection with the McCord Canal and to the Calloway, so that surplus waters are readily delivered to these lower canal systems. The territory commanded by this canal, lying between it and the Calloway, is about 33,000 acres, which includes between 6,000 and 7,000 acres formerly served by the McCord Canal.

McCaffery Ditch.—The mention of the McCaffery Ditch as an independent irrigation work is merely historical. It is a small ditch diverting water from the south side of the slough known as McCaffery or Calloway Slough, which has been made a part of the well-known Calloway Canal. The ditch is several miles long, 7 to 8 feet wide, and 2 to 3 feet deep. It was constructed in 1873, and is still in use as a distributary of the Calloway Canal water. The use of its water is confined to the island lying between Calloway Slough and the main channel of the river.

McCord Canal.—This canal, which has a position intermediate between the Beardsley and Calloway canals, was built, in part at least, in 1875 and 1876. A diversion of water was made from the north side of Kern River, about 2 miles below the head of the Kern Island Canal, into a natural high-water channel, and from this natural channel the canal proper was carried 3 or 4 miles northward. In 1879 the canal was reported to be about 4¼ miles long, with three branches, aggregating 10 miles in length. Its bed width was noted at 20 feet and its depth at 2 to 3 feet.[1] The canal was provided with a new head gate in 1882 and was extended northward. The main canal had a total length of about 12 miles. The district commanded by the canal is now served with water from the Beardsley Canal, and no attempt is made to maintain the McCord Canal as an independent work.

Calloway Canal.—This is the principal canal for the irrigation of lands on the north side of Kern River. Its purpose was primarily to supply water for the reclamation of lands entered as desert claims. Almost as soon as the notice of intention to make the diversion of water for this canal had been posted at the head of McCaffery Slough, in the spring of 1875, all individual rights were assigned to the Calloway Canal Company, known on the records as the Kern River Land

[1] See Rept. State Engineer, Wm. Ham. Hall, 1880, Appendix to Part IV, p. 77.

and Canal Company, and no time was lost in commencing construction, which was pushed forward rapidly until Poso Creek had been crossed by the main line of the canal. The diversion from the river was effected at the head of McCaffery or Calloway Slough, which was corrected in alignment so far as necessary and cut to a uniform width of 120 feet. The upper 2½ miles of the slough were thus appropriated for canal purposes. Thence an artificial channel 60 feet wide on the bottom was cut in a northerly direction. At between 2 and 3 miles from

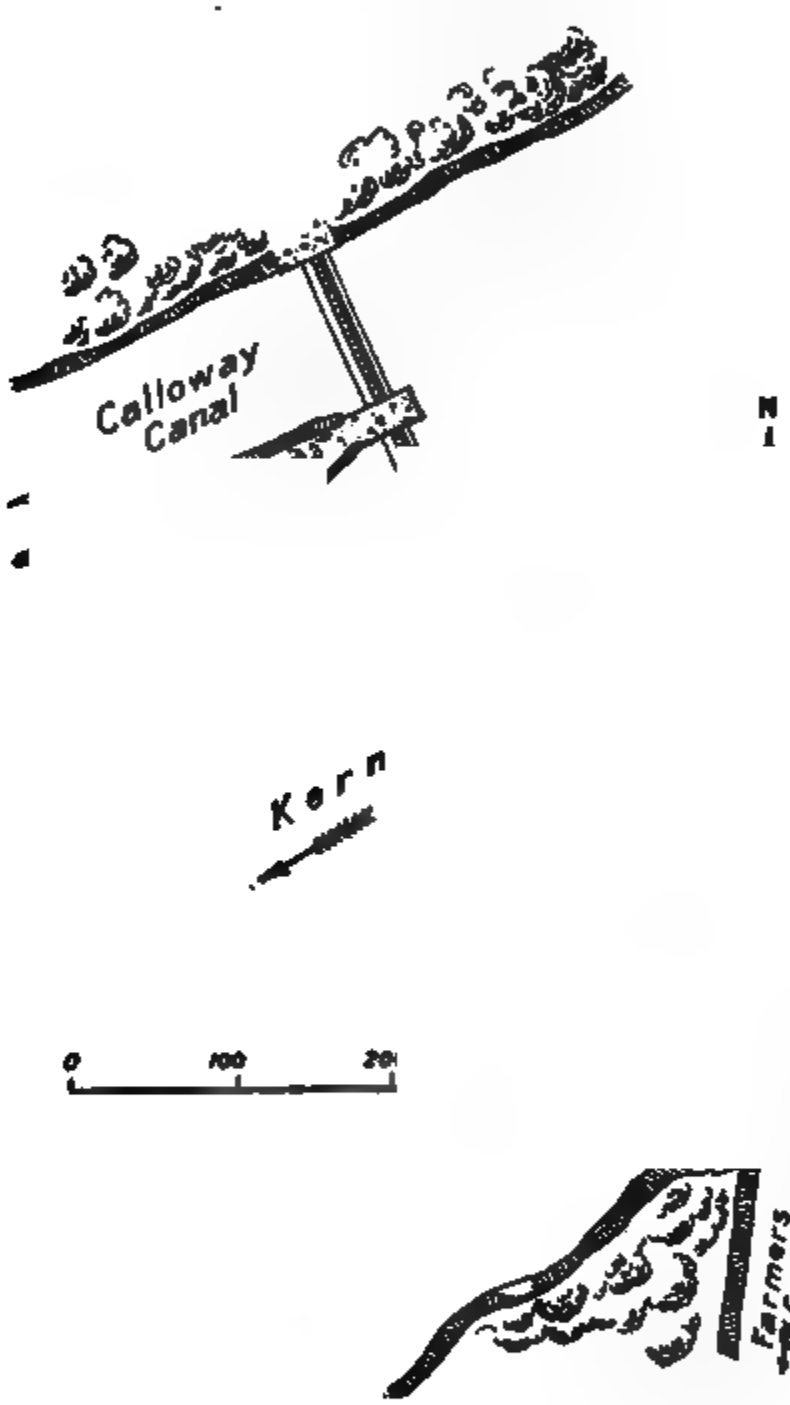


FIG. 8.—Head of Calloway Canal.

the slough the width of the canal was increased to 80 feet on the bottom, and it retained this width to Poso Creek. To the north of Poso Creek the canal extension is 60 feet wide. The canal has a fall of 0.8 foot to the mile northward from the point where it leaves McCaffery Slough for a distance of about 15 miles; thence to and beyond Poso Creek the fall per mile is only 0.4 foot. The total fall from the head of McCaffery Slough to the point where the canal proper leaves the slough is about 10 feet. The inflow into what is ordinarily called

WEIR AND REGULATOR, HEAD OF CALLOWAY CANAL

the head of the canal, being the original head of McCaffery Slough, is controlled by a head gate or regulator. Where the canal proper leaves the slough a check weir, serving the purpose of a waste gate, closes the latter and affords convenient control of the water-surface elevation at that point. A second regulator is put into the head of the artificial channel, which leaves the slough just above the check weir. Sands accumulating in the slough channel above the lower barrier are readily sluiced out by removing the loose flashboards of the weir and permitting a free flow through the lower section of the slough back to the river.

The distribution of water from the Calloway Canal is effected by means of branch ditches or laterals, which are generally carried westward in the direction of the greatest slope of the valley plain. Their position is usually determined by that of gentle swells or ridges, which afford the best command of the lands to be irrigated. These laterals are ordinarily about 16 feet wide. Their banks are made high, so that inundation of adjacent territory can readily be accomplished. The natural fall of the valley surface in the direction of the laterals is 7 to 20 feet to the mile. This is reduced by means of check weirs or drops to less than 2 feet, effective, to the mile. Tenants of land to be irrigated from these laterals are reported to have frequently taken contracts for their construction as low as 5 cents per cubic yard of earthwork.

Late in 1879 Mr. F. R. Fillebrown, engineer in charge of canal construction, reported an expenditure of $78,165 on the main canal, and $49,460 on about 64 miles of laterals. The area covered by the 64 miles of laterals was reported at 16,160 acres, and the cost of laterals, with gates complete, per acre under ditch was $4. The cost of constructing check levees in this district for irrigation by flooding was given at $2.15 per acre. Water was first turned into the Calloway in 1875, but at that time the principal purpose was to moisten the canal bed and thereby facilitate excavation.

All structures on the canal are extremely simple, but efficient. The head gate or regulator now in use was constructed in 1884, late in the season, after a first freshet had floated the original head gate out of place. The gate was designed and built by Mr. L. F. Colton. While work on it was in progress a large portion of the dam or weir across the river at the head of the canal was washed away, and this was replaced under some difficulty, as the river rose before work was completed and flooded the foundation pit. Much of the flooring had to be nailed under water. The weir or dam across the river is a very light structure, of the open type, resting upon a floor which is the top of a large sand box extending across the river. The weir proper consists of a set of rafters, 4 feet apart from center to center, supported by a set of shores or braces, forming a light framework, and the necessary flash or drop boards for the closing of the spaces between rafters. The rafters were

originally inclined at an angle of about 40 degrees, but when it was found desirable to raise the weir crest somewhat they were placed more nearly erect. They are cut off horizontally at the top and afford support to a single-plank footbridge, each plank of which is held in position by a dowel in the top of the weir timber. This arrangement was adopted to secure a proper spacing of the weir timbers at their tops. The drop boards are of light, 1-inch thick material. According to the original design, the entire superstructure was movable. A set of brackets has been attached to the weir frames below the footbridge to support the drop boards, which are out of service. The total length of the weir was originally 500 feet, of which only the northernmost 400 feet was rebuilt in 1884; the rest, extending from a small island in the river to the south bank, has been replaced by a solid earth, or rather sand, fill. This part of the weir had a superstructure of a type different from

Fig. 9.—Plan of head gate of Calloway Canal.

that of the new weir. Its floor of 2-inch planking rested upon two lines of sheet piling, and the floor joists received additional support from intermediate piles. The river bed at that point, to an unknown depth, is a clean, moderately fine sand, with which all voids under the flooring were compactly filled.

With some variations in detail of construction the river weir is prolonged in a direct line northerly across the head of the Calloway Canal; but the timbers of the Calloway Canal regulator are somewhat heavier than those of the weir. Its frames are not movable. The main timbers are 6 by 8 inches, and have several supports each 6 by 6 inches. The canal regulator is 100 feet long, having 25 openings, or bays, each 4 feet from center to center of gate frames. The drop or flash boards are 1 by 6 inches.

A CALLOWAY CANAL.

B. IRRIGATING ALFALFA IN CONTOUR CHECKS.

At each end of the Calloway weir and of the canal regulator the banks are protected by timber bulkheads, sheet piling, and brushwork.

A full flow of water is expected in the Calloway Canal during the months February to May, inclusive. At the low stage of the river the canal is entirely dry. The maximum capacity of the canal, estimated some years ago from dimensions below McCaffery Slough, was about 550 second-feet, but the ordinary full flow is 450 to 500 second-feet. More water than this in the canal renders liability of breaks in the banks too great.

The canal laterals have been extended throughout a district having an area of about 60,000 acres, nearly all of which may be considered fully prepared for irrigation and actually irrigated each season. The principal crop irrigated is alfalfa. A view of a large field of this forage crop being irrigated by means of contour checks on the Jackson Ranch is shown in Pl. XII, *B*. No water was sold from the Calloway Canal

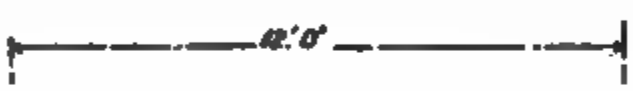


Fig. 10.—Section of head gate of Calloway Canal.

until the sale of lands owned by the Kern County Land Company (J. B. Haggin and Lloyd Tevis) commenced.

Emery Ditch.—This is a small ditch making a diversion of water from the north side of Kern River about 4 miles below the head of the Calloway Canal. It was constructed in 1877 as a private ditch by Mr. R. K. Emery, and was only 3 miles long, 6 to 8 feet wide, and 2 feet deep. The diversion of water was effected by inexpensive brush wing dams, a new one being required after each freshet. Notwithstanding a capacity of 10 to 20 second-feet, but little irrigation was ever accomplished with this ditch. It was difficult to force the necessary water into the ditch even at moderately high stages of the river; the loss of water in transit to lands to be irrigated was considerable, as the route of the ditch was across a sandy region, and the drifting sands made it difficult to keep the ditch open.

Jones & Tuckey Ditch.—The description of this ditch, like that of a number of the other lesser irrigation works from Kern River, is hardly more than a historical note. The ditch was next below the Emery Ditch, on the north side of the river, and followed a parallel route northward. It was about 10 feet wide and 4 miles long. It was constructed in 1876, but fell into disuse seven or eight years later, when it came under control of the principal owners of the larger canals commanding the same territory. Its rights have been merged with those of the larger canals.

Railroad Canal.—At the head of a natural high-water or overflow channel on the north bank of Kern River, known as Goose Lake Slough, three cuts have been made to afford a greater inlet capacity to the head of the slough. The uppermost of these is known as the Railroad Canal. It is about one-half mile long and 25 to 30 feet wide on the bottom. This canal, if such a designation may be applied to the diversion, was constructed late in 1875, and a light timber barrier 40 feet wide (8 bays, each 5 feet) was placed across its head for the control of its flow. The water diverted from the river into this channel was for the irrigation of lands (desert-land entries) near Goose Lake Slough belonging to persons who had failed to secure rights in the Goose Lake or the Wible canals. Very little irrigation was accomplished with it, except the natural wetting of lands adjacent to the slough. Only 320 acres of the lands for which water was claimed through the Railroad Canal are said to be still served with Kern River water.

Wible Canal.—Just below the Railroad Canal is another cut from the river to the slough, which was made in the summer of 1875, by another set of persons, who were desirous of using Goose Lake Slough as a main channel to carry water to their lands. This cut was only 1,000 to 1,500 feet long. It was 30 to 35 feet wide on the bottom and about 2 to 3 feet deep. Its head gate was 56 feet wide. The first cost of the canal is reported at $3,500, and the cost of the regulator at $500. Water is apportioned to stockholders without any elaborate system of measurement. Expenses of management, which are light, are apportioned to the consumers of water by mutual agreement.

Goose Lake Canal.—First in the order of time of construction, but third in position, is the enlarged original head of Goose Lake Slough, known as the Goose Lake Canal. This is located on the north side of Kern River just above the Pioneer Bridge, about 7 miles in a direct line west of Bakersfield. In 1874 the head of Goose Lake Slough was cleaned out and enlarged and a regulator was built across it. This regulator is 134 feet wide. The head of the slough was 150 to 160 feet wide. This work has always been under the control of the parties who controlled the principal large canals already enumerated and has not been in use to any considerable extent for systematic irrigation.

A. PIONEER CANAL WEIR, KERN RIVER.

B. PIONEER CANAL.

Pioneer Canal.—This canal was constructed in 1873 by settlers upon lands on the north side of the river below the Pioneer Bridge. It was originally made 30 feet wide at its head for a distance of a little over 100 yards; there its width was decreased to 10 or 12 feet. Subsequently, however, the canal was enlarged to a bed width of 30 feet throughout a length of 7 or 8 miles, and its upper sections were still further enlarged in 1879, when the canal was made 60 feet wide. From its head at the Pioneer Bridge the canal has a westerly course, its waters being used principally upon the Kern County Land Company's tract of land. The canal capacity reported for this canal by Mr. W. R. Macmurdo, C. E. (in charge of canal work in 1880), was 450 second-feet, and its cost about $44,000.

The head gate of this canal offers some points of interest. It rests upon sand. A trench was excavated across the canal, 14 feet wide

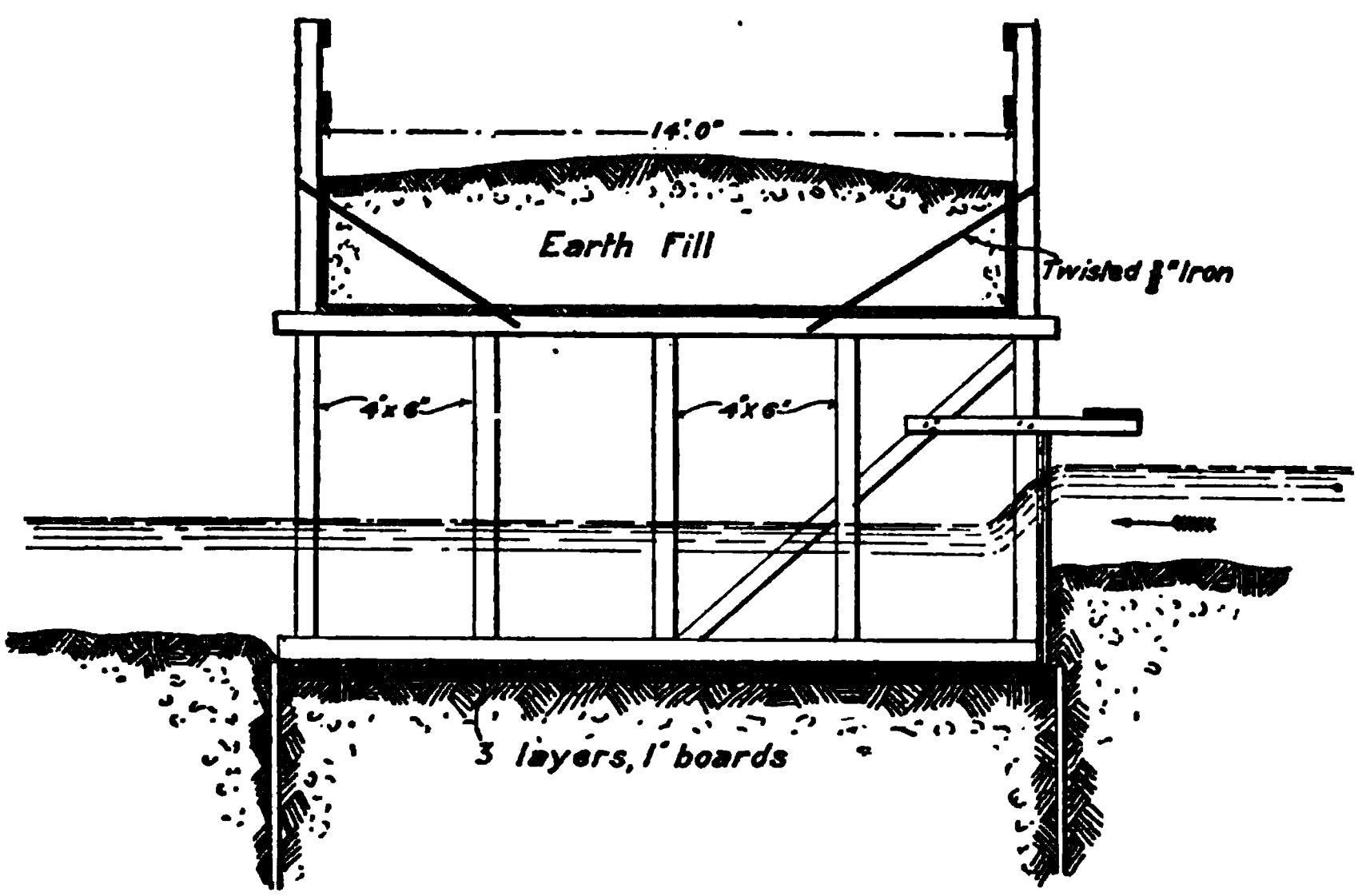


FIG. 11.—Section of Pioneer Canal regulator.

(14 by 60 feet) and 3 feet deep. Light sheet piling was driven on the four sides of this trench 1 foot deep. To the top of the sheet piling were nailed 2 by 4 inch timbers at the height of the canal grade. The trench was then refilled and 1 by 6 inch pine boards were laid across the top of the filling 4 feet apart, in the direction of the canal axis. Floor boards 2 inches thick were thereupon nailed to the pine strips and extended over the side walls of the trench. They were laid across the axis of the canal. On this floor sills 4 by 6 inches were placed on edge, 4 feet apart, for the support of 4 by 6 inch posts, which serve as bridge posts. The bridge floor is 2 inches thick and covered with an earth fill 3 feet thick, which serves to give weight and stability to the entire structure. The sides of the bridge, acting as retaining walls for the earth fill, are tied to the floor joists by means of three-eighths-inch

iron rods, twisted together for tension. The upper bridge posts support the loose flashboards by means of which the structure is converted into a regulator. This is one of the best examples of a cheap, efficient structure. Its total cost was only $540, including all earthwork. It was built in 1884 by the engineer in charge, Mr. Walter James. The weir in the river at the head of the Pioneer Canal was originally a combination structure. The weir posts supported a bridge, toward the construction of which a money contribution was made by Kern County. The original weir has been replaced by a late structure, crossing Kern River just below the Pioneer Bridge. This is very similar in arrangement to the one at the head of the Calloway Canal. It controls the water-surface elevation in the river for a number of canals and ditches besides the Pioneer Canal, including the Goose Lake Slough system on the north side of the river, and the Wilson and Meacham ditches on its south side.

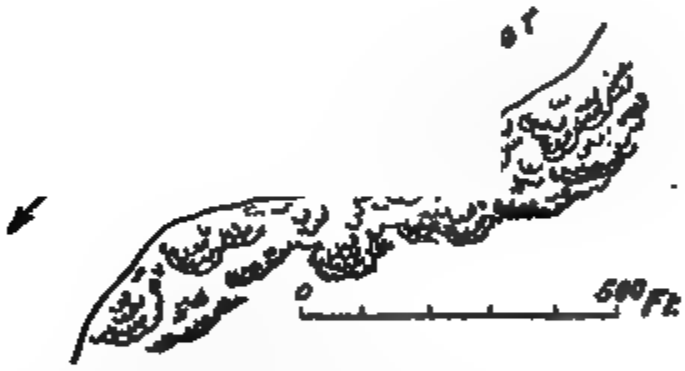


FIG. 12.—Head of James & Dixon Canal.

Edwards Ditch.—This ditch, whose head is about a mile below the Pioneer weir, is to be classed with those of lesser importance. It was constructed in 1875. Work may have commenced late in the preceding year. The ditch was about 2 miles long, and 10 to 12 feet wide on the bottom. It fell into disuse in 1879, but was reopened in 1885. It was then in use by several persons, but received water only at high stages of the river.

James & Dixon Canal.—This name has been applied to a cut about 2½ miles below the Pioneer Bridge, from Kern River into Johnson Slough (one of the river's north-side delta channels). This cut was excavated in 1872 and 1873. It was less than half a mile long, and was originally made 30 feet wide on the bottom. In 1884 it was connected, at a point about 200 yards below its head, with the Johnson Cut, a second opening from the river into Johnson Slough. The water delivered into the slough by the James & Dixon Cut is for use on portions of the McClung Ranch and on the Buena Vista Ranch. The slough is

used in common by the owners of the two canals for about a mile below the point where their waters are mingled. The Johnson Canal water is there taken out of the south side of the slough for distribution to irrigators, while the James & Dixon Canal water flows on down the slough channel.

About 1882 it became necessary to establish a better control of the flow of water into Johnson Slough. To this end a reasonably permanent wing dam was constructed just below the Johnson Cut, and a new head gate, or regulator, was placed in that cut. The wing dam was in the form of a timber weir extending halfway across the river channel and resting against a small island. The space between its end and the south bank of the river was closed annually at the low-water stage by an inexpensive sand dam. The water was thus forced over the weir and brought under control. The control at high stages was not essential. This work was carried out under the direction and management of the owners of the James & Dixon Canal, and a proportional part of the cost—$2,200 out of a total of $4,700—was contributed by the owners of the Johnson Canal. The water supply for both canals was thereafter drawn through the same regulator.

The original purpose for which the James & Dixon Canal was constructed was to supply water for irrigation to the Buena Vista Ranch, then owned by Mr. James Dixon, and to lands in its vicinity. The canal and the lands to be irrigated by it have long since become a part of the property under control of the Kern County Land Company.

The combined capacity of the James & Dixon and the Johnson canals has been estimated at 400 to 450 second-feet. The head works of the James & Dixon Canal are now out of service, because it has been found more convenient to supply water to the lower section of the canal through a branch of the Pioneer Canal.

Johnson Canal.—Several hundred feet below the original head of the James & Dixon Canal is the cut from the river to Johnson Slough known as the Johnson Canal, which is owned by the Lower Kern River Irrigating Company. It was constructed in 1873 and is about one-eighth mile long. It was described by Mr. James D. Schuyler, in his report to the State engineer, as being 10 feet wide on the bottom, 3 feet deep, with bank slopes of 1 on 2; but greater original dimensions are claimed for it by resident engineers of Kern County. The canal water, as already noted, flowed about a mile in Johnson Slough and was then taken out for delivery to irrigators. The separation of its water from that of the James & Dixon Canal was effected and controlled by means of regulators, one being placed in the slough, another in the artificial channel. There was no sale of water to consumers. The canal owners took water as they needed it, and expenses of canal management were apportioned. The cost of maintaining head works at the river was borne in part by the owners of the James & Dixon Canal. Water is now delivered to the lands served by the Johnson Slough Canal

through branches of the Pioneer Canal, and the use of the canal head works has been abandoned.

Ashe Ditch.—This ditch, which fell into disuse about 1882, was a small one, belonging to a private owner, and was constructed about 1874 or 1875. Its head was on the north side of the river, just below the Johnson Canal. It had a westerly course, was about 1 mile long, 8 feet wide on the bottom, and 2 feet deep. Its mention is merely historical.

May Ditch.—This ditch was in use for several years subsequent to 1874. Its length was 2 miles, its course westerly, its width about 8 feet, and its depth 2 feet. Its head works were 4 to 5 miles below those of the Johnson Canal. Whether it is now in use is not known.

Joice Canal.—There is some confusion among names applied to the ditches of Lower Kern River which were intended in whole or in part to supply water to the Buena Vista Ranch. In 1873 the lands known by this name were owned by the late W. C. Ralston, and were under the management of James Dixon. The first diversion made for their irrigation was in that year, from a minor north-side delta channel of the river known as Gage Slough. The ditch was 12 feet wide, and was intended to carry water about 2 feet deep. To increase the flow of water in that branch of Kern River upon which Gage Slough was dependent, a dam of brushwork was constructed across the most southerly of two channels into which the river separated a short distance above the head of Gage Slough. Still later, in the same year, a second ditch was constructed from the north side of the river above the slough, and this was connected with the first ditch. The head of Gage Slough was then closed permanently.

Two years later a private ditch was constructed as a branch of the Joice Ditch, commencing about 2 miles below the head of the latter. This was known as the Dixon Ditch, and has led to the use of the name Joice & Dixon Ditch for that part of the original Joice Ditch above the Dixon Ditch. The uncertainty as to amount of water covered by recorded claims, and the procedure in Kern County leading to the granting of a canal franchise, are well illustrated by the Joice Canal. A notice was posted on April 28, 1873, in sec. 21, T. 30 S., R. 25 E., Mount Diablo meridian, by Messrs. E. V. Joice and James Dixon, of a claim to 10 cubic feet of the water of Kern River, measured under a 4-inch pressure. On May 26 of the same year the same persons posted another notice of claim to 20 feet of water, measured under a 4-inch pressure. These claims were followed in 1878, on October 7, by another by Mr. William B. Carr, posted on sec. 23 at the head of Joice Canal, to 6,250 inches of water, measured under a 4-inch pressure. He was on the following day granted a franchise by the supervisors of Kern County, acting in the capacity of water commissioners, to construct a new canal 30 feet wide on the bottom, 2 feet deep, and having a cross-sectional area of 72 square feet, or to enlarge any canal acquired by

him to these dimensions for the purpose of diverting the amount of water named in his claim. The franchise then obtained was transferred a few days later to the Joice Canal Company.

From a report made in 1879 by Mr. W. R. Macmurdo, one of the engineers in charge of canal work, to Messrs. Haggin & Carr it is learned that the cost of irrigation with water of this ditch, after ditches and checks were all constructed, was as low as 10 cents per acre. The lands commanded by the canal can also be supplied with water from the Pioneer Canal and from the James & Dixon Canal, as has been already explained. The Joice Canal receives water only during comparatively high stages of Kern River. A timber weir extending partially across the river was maintained for a number of years, but it has recently been found more convenient to abandon the canal head works and to supply it with water from the Pioneer Canal.

Dixon Canal.—Two years after the construction of the Joice Canal the branch known as the Dixon Canal was carried in a northwesterly direction, for the irrigation of a small tract of land on the margin of the lands segregated as swamp and overflowed, and thereafter the upper portion of the Joice Canal, about 2½ miles long, was regarded as the common head of the two ditches. The ditch was described by Mr. James D. Schuyler in 1880, in his report to the State engineer, as being 2½ miles long, 6 to 8 feet wide on the bottom, and 1½ feet deep.

Kern Valley Water Company's canals.—For the reclamation of the lands in the upper or southeastern portion of Buena Vista Swamp two large canals were constructed, one upon either side of the long, narrow trough of the valley through which the overflow waters of Kern and Buena Vista lakes took a northwesterly course toward Tulare Lake. Of these two canals, the one on the west side was intended as a recipient of the flood flow, and was therefore given magnificent dimensions. The other canal was to serve more particularly as a source of supply for irrigation water. Both of these canals were connected with Buena Vista Slough, a natural channel of irregular alignment and variable dimensions, which has a northwesterly course from Buena Vista Lake for a distance of about 8 miles to the vicinity of the canal head works, near which point its channel becomes more or less indefinite.

At the time these canals were constructed, about 1875, it was proposed by their projectors to convert Kern and Buena Vista lakes into great storage basins of water to serve for the irrigation of lands to the northwest. But this proposition met with opposition. Other claims to the lakes were advanced. The lake beds were claimed as swamp and overflowed land subject to reclamation by drainage. Long litigation ensued, involving among other things the question of riparian ownership in the waters of Kern River, as it was manifestly to the advantage of the owners of lands in Buena Vista Swamp to prevent diversions in the upper sections of the river, so as to augment the flow through natural channels into Buena Vista Lake and thence into the channels

from which the lower canals were fed. As a result of this litigation it was definitely determined that the doctrine of riparian rights prevails in this State; and, more directly bearing upon the questions at issue, it led to an agreement between the conflicting interests according to which the use of lake surface for reservoir purposes was restricted to Buena Vista Lake, and some definiteness was given to the rights of the various canals to make diversions of the Kern River water.

As soon as this result was reached, in 1891, work progressed rapidly on the structures necessary to dam off Buena Vista Lake toward the east and to control the outflow of its waters toward the north. The storage capacity of the lake is represented to be 150,000 acre-feet, being presumably the amount actually available for irrigation purposes when the lake is full. The alignment of the principal channel of Kern River in its course toward the lake has been corrected, and it is separated by means of high embankments from a return channel correspondingly correcting the alignment of Buena Vista Slough. With-

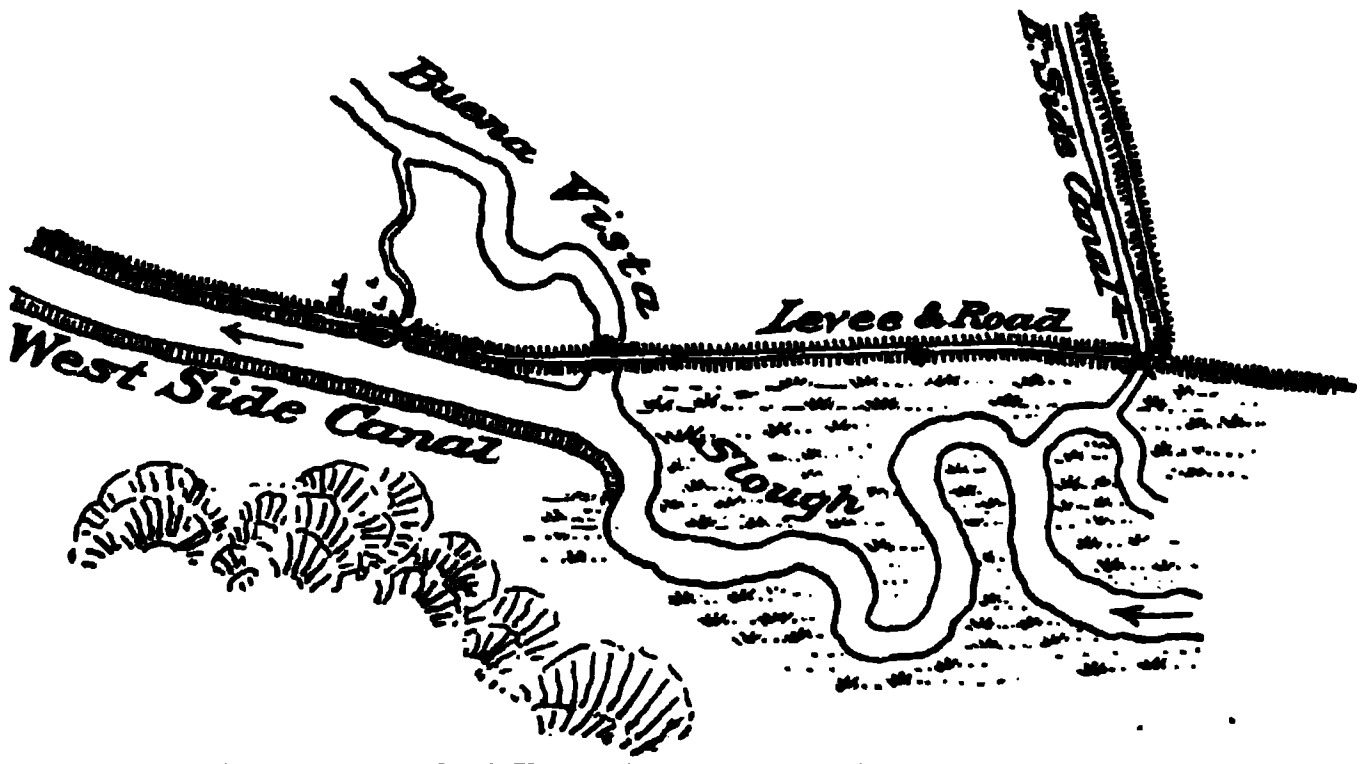


FIG. 13.—Head of Kern Valley Water Company's canals.

out any definite information concerning the cost of these works, it is not unreasonable to suppose that it has exceeded $250,000, in addition to over $300,000 for original canals.

The west-side canal was made 125 feet wide on the bottom and was planned to carry water 7 feet deep. The position of the canal along the western border of the swamp gave it a fall of about 4 to 5 feet to the mile, which was reduced by means of check weirs or drops. Four of these were constructed, but three were washed out, and but a single one remains to serve as a regulator. The canal has a length of 24 miles, covering more than one-half the distance toward Tulare Lake, and discharging at its lower end upon the lower portion of Buena Vista Swamp. The east-side canal is 25 feet wide and has a depth of 3 to 5 feet. A regulator has been placed in it where it is crossed by the road embankment, which serves as a barrier against flood waters of the river or slough from the south. The regulator is a combination of a bridge

with earth fill on top and a gate. The gate is of the ordinary vertical flashboard type.

Where water is to be drawn from the main west-side canal for irrigation purposes it is admitted to distributing ditches by means of wooden box culverts placed under the canal levee.

Maintenance of the works has involved frequent bank protection on the main canal, the bottom of which below its regulator has been irregularly eroded.

Flood waters have frequently made dangerous inroads upon banks and levees where the canal lies in the light alkaline soils of the west side, which do not afford much resistance to the erosive action of the water.

The irrigation from this canal system is still confined to the alfalfa fields at the head of Buena Vista Swamp between the two main canals. Here about 20,000 acres of alfalfa, in one continuous tract and under one ownership and management, represent the extent of the water's use.

The system of irrigation is the contour-check system. The contour levees have usually 6 inches difference in elevation, or a little more. The soil is a black vegetable mold, 4 to 6 inches deep, under which is a heavy clay subsoil. Checks are generally 8 to 10 acres in area. Small checks are preferred, and some of the larger ones are being subdivided. Some drainage of the land after flooding is necessary and drain ditches are provided for the purpose. The cost of preparing the land for irrigation, including the cost of small ditches, was about $10 per acre.

KERN AND TULARE IRRIGATION DISTRICT.

No work of actual construction was done on the proposed canal system for this irrigation district, now disorganized, but as the contemplated source of water supply was Kern River the project requires mention. The district was located on the east-side valley plain surrounding Delano, in Kern and Tulare counties, about 25 miles northward from Kern River. It had an area of 84,000 acres. The proposed main canal was to have a bed width of 40 feet, a water depth of 4 feet, a fall of 9 inches to the mile, and a total length of about 55 miles. The diversion from the river was to be made about 8 miles above the head of the Beardsley Canal, on the north side of Kern River, and the route of the canal was to be westward along the bluffs and broken slopes of the hills for about 7 miles, to where it emerged upon a comparatively smooth plain at the base of the hills, thence northerly across Poso Creek and Dyers Gulch, to and across White River. The estimated cost of the main canal was $426,000 and of the necessary distributaries $195,000. The district was organized in 1890, and a bond issue of $700,000 was intended to cover cost of works.

WATER SUPPLY, DISTRIBUTION, AND MEASUREMENT.

The breadth and shallowness of the bed of Kern River, whose banks are only 3 to 6 feet high, facilitate diversion of its water. The lands irrigated have already been described.

Diversions are numerous both toward the north and toward the south, and are usually effected by the use of light, movable, open-work timber weirs, above which water is forced into the head of a ditch or canal. The flow in the canals is controlled by gates or regulators, usually of the inclined or vertical flashboard type.

The canals on the north side of the river have an aggregate capacity of several thousand second-feet; those on the south side, between 1,000 and 2,000 second-feet.

Most of the Kern River canals were constructed for the irrigation of particular tracts of land, and therefore received alignments as direct as possible from the point of diversion to the land to be irrigated. Their location in a position to command as much land as possible is exceptional. The Kern Island, Beardsley, McCord, and Calloway canals are among the exceptions. On Kern Island the course of the canals is generally in the direction of the greatest slope of the ground's surface. As this slope is represented by a fall of about 7 feet to the mile, and the soil is generally easily eroded, check weirs or drops are necessary to check the flow of water in the canals and to render diversion into laterals possible. Such structures are about one-half mile apart on the principal original branches of the Kern Island Canal. There are 25 of them in the main channel of the Stine Canal, and about the same number on the Buena Vista Canal. The James Canal has 14.

Despite the various names assigned to the Kern River canals and to the corporations which own them, the conflicting interests thereby indicated do not all exist. Almost the entire canal and ditch system of this river has passed into the control of the two great proprietary firms, Haggin & Tevis and Miller & Lux, and contentions as to water apportionment are usually restricted to broad questions affecting whole districts rather than individual diversions. Until a satisfactory allotment of the low-water flow of the river was agreed to by these firms, comparatively little attention was paid to perfecting a system of water apportionment either from the river or from the several canals. It was the rule for each irrigator to use water as he required it, so long as water was available. The only canal from which water was sold until within the last few years was the Kern Island Canal.

The plan of apportionment of water in the case of the Beardsley and the other canals owned by joint stock companies, stock being held by landowners, gave to each stockholder a part of the water in the canal proportional to the amount of stock owned, but the distribution was based on approximation, without attempting measurement of the water delivered.

The allotment of water to the irrigators from the Kern River canals is in charge of canal superintendents, who are assisted by ditch tenders, locally called "zanjeros." The canals are inspected daily, and the water applied for by irrigators is delivered into their irrigating ditches. Water is sold by measurement, being delivered through measuring boxes.

Before 1875 water was furnished free of charge from the Kern Island Canal to irrigators, in order to encourage its use. During the years 1875 to 1877 it was sold at 1¼ cents per 24-hour inch (miner's inch, supposed to be under 4-inch pressure, equivalent to about 0.02 second-foot), aggregating about $1.50 per acre per annum, as then used for the various crops cultivated. In 1878 the rate was increased to 1½ cents per 24-hour inch. In 1879 the Kern Island Canal Company charged the following rates for water:

For general farming: April to November (inclusive), 1½ cents per inch under a 4-inch pressure, for twenty-four hours. December to March (inclusive), 1 cent per 24-hour inch.

For market gardens: For 12-inch stream and upward for not less than one-half month, 2 cents per inch per day of twenty-four hours. For 48-inch stream and upward for one day or more, 2 cents per inch per day of twenty-four hours.

For house lots and gardens: 12 inches for one day of twelve hours, or 24 inches for one-half day of six hours, $1; 12 inches for one night of twelve hours, 75 cents; 12 inches for one-half day of six hours, or 24 inches for three hours, 75 cents; 24 inches for one day of twelve hours, $1.50; 24 inches for one night, $1.25; 24 inches for one hour, 50 cents.

The prices now charged vary somewhat for the different canals, being adjusted according to operating expenses. They range from about 30 to 75 cents per second-foot for twenty-four hours, and in exceptional cases have been below the lowest rate named.

The original measuring box was so constructed that a uniform head, over an aperture which could be adjusted to the number of inches called for, could be maintained. The area of the aperture was controlled by means of a horizontal sliding board. It was 4 inches in height, and the surface of water above the aperture was maintained at 4 inches above its top. Water had an unobstructed outfall through the aperture.

This gate was superseded by a well-constructed overfall weir. Water is admitted to a chamber above the weir by means of a gate which affords control of the water elevation. The depth of overfall is determined by measurements to the water surface above the weir from a carefully set "level-board." The cubic foot per second, or second-foot, has recently been substituted for the inch as the unit of measurement. At the present time gates with submerged orifice are preferred and are coming into general use.

On the South Fork Canal no system of measurement has been introduced. Each consumer takes what he requires when there is an abundant flow in the canal. When water becomes scarce, a canal superintendent is employed to apportion the water to the canal stockholders.

The same lack of system in water measurement prevailed for a long time on the Pioneer, the Beardsley, and many other canals before they passed entirely into the ownership or under the control of the large water corporations.

METHODS OF IRRIGATING AND DUTY OF WATER.

Alfalfa and cereals are still the principal crops irrigated with Kern River water, although during a few years orchard and vineyard areas increased rapidly in the colony tracts north of the river. The demand for water for the large areas represented by the alfalfa and wheat fields has led to special effort to minimize the expense of applying water to the soil. The system of wetting the soil for these crops is generally by flooding, which is accomplished in various ways. The most primitive system, rapidly falling into disuse, is that of spreading water over the surface from small temporary ditches, sometimes mere plow furrows, located on high ground, and controlling the overflow from these. Skill is required to cover the whole surface with water; the progress of irrigation is slow and the system is expensive because much labor is required to control the water. The only advantage of this system is that its first cost is small.

Irrigation by flooding in rectangular checks is confined to occasional orchards and vineyards and small tracts of alfalfa. The favored method of applying water is by flooding in contour checks. Low, flat embankments, generally 1½ feet in height, rarely 2 feet, are thrown up, which closely follow contour lines, and the spaces between these are divided into compartments or checks by means of cross levees. The areas of these checks range from less than 1 acre to 60 acres. When a tract of land checked in this way is to be irrigated, water is admitted to the highest checks first, and as soon as the flooding of a highest check is complete its water is drawn off through suitable gates to the one next below, into which the irrigating stream is turned at the same time.

The labor attached to this system of irrigation is much less than that required by the method of wild flooding, but the first cost of preparing land is considerable. The cost of land preparation will of course depend upon the smoothness of the surface and its slope; also upon the character of the levees between compartments. The best form of these levees has a base 16 to 24 feet in width and slopes so flat that any kind of farming implement may cross them in any direction.

The following example of cost of land preparation and ditching under the Calloway Canal has been taken from notes by Mr. James D. Schuyler:[1]

The average cost per acre of 5,956 acres prepared in this way was as follows: Earthwork, $1.64; waste or drainage gates, $0.51; total, $2.15. The average cost of lateral canals, including necessary regulators and side gates to supply the land, was $4 per acre, making the total cost of preparation of ground $6.15 per acre.

These check levees are built upon 1-foot contours with about 20 feet base; the lateral canals are from one-fourth to one-half mile apart, and the checks range from ten to fifty acres in area. From 15 to 20 miles of check levees are required per square mile of land, and a mile of levee contains 3,080 cubic yards. The soil is a sandy loam, easily worked, and the cost of preparation shown above is probably less than the average cost of such works elsewhere.

The laterals can supply water to the checks between them at a rate generally between 100 and 200 second-feet, the amount of water ordinarily admitted at one time into a check being about 50 to 70 second-feet from each of the laterals between which it lies. The contours on which the levees are constructed are from 0.5 to 1 foot apart in vertical elevation. One foot was first adopted as the vertical distance between contours, but experience has proved it to be better to reduce this distance, thereby making the water more controllable and at the same time reducing the area of the checks.

In filling large checks water stands long on the lowest ground. It is customary to draw it off into the next check as soon as the whole surface is submerged. But it is found that the portion of the check submerged for the shortest period of time produces a crop equally as good as that from any other portion. All percolation in localities where water stood more than the minimum time allowed for the high places is therefore a waste of water. This waste in large checks is frequently so great that a check can hardly be filled, as water is lost by percolation almost as fast as supplied. Economy of time and water would therefore seem to demand checks smaller than those in common use at present to the north of Kern River, where the average area of checks is about 8 to 10 acres. Moreover, the use of lower check levees reduces the obstructions offered by the check system to farming operations.

It can be shown by mathematical demonstration that there is considerable loss of water and of time when porous soils are irrigated in large checks, but an example will suffice.

The irrigation of a 60-acre check of alfalfa with water from the Calloway Canal commenced at 5 o'clock p. m. on May 12, 1885. All parts of the check were covered and irrigation was complete about 8 a. m. on the following day. No accidents causing loss of water had occurred. The amount of water entering the check was stated to have been about 250 second-feet (one-half the amount then flowing in the Calloway Canal). This is presumed to be an overestimate, and it will be safe to say that at least the maximum amount ordinarily delivered from two

[1] Rept. State Engineer of California, 1880, Part IV, App., p. 85.

laterals was entering the check. This amount would be about 150 second feet.

During the time required to accomplish the irrigation of these 60 acres the amount of water entering the check was sufficient to have covered it to a depth of over 3 feet, while the amount in the check when its irrigation was complete, and which was in part available for irrigation in lower checks, had an average depth of about 0.75 foot. The total amount absorbed was therefore over 2.25 feet, and it must be presumed that much more water sank into the ground in those parts of the check which were lowest and had water standing on them fifteen hours than in those parts which were highest and were submerged only from two to three hours.

For economic irrigation the volume of water applied and the areas of the checks should be so adjusted that no portion of the check will be under water more than twice as long as the period of desirable inundation. In porous soils the full head of water can generally be allowed to flow into a check until irrigation is complete. In heavy soils there is less danger of excessive waste, absorption by the soil is less rapid, and the head of water may be reduced as soon as the whole surface of the check is submerged. A rapid delivery of the surplus water from an irrigated check into the one next below it is essential to economic irrigation by the contour-check method.

Irrigation from the Calloway Canal in May, 1885, was progressing at the rate of 200 to 400 acres per day. The flow of the canal was 450 to 475 second-feet. In other words, the irrigated tracts were receiving water at the enormous gross rate of 130,000 cubic feet per acre, equivalent to an average depth of about 3 feet over all lands irrigated.

A new system of irrigation by flooding has recently been tried on some of the land commanded by the Calloway Canal. This system consists in the construction of parallel levees which follow lines of greatest slope at short intervals. These levees are low, not over 1 foot high, and are placed 50 to 200 feet apart. There is between each two a long, narrow strip of land, crossed at intervals by a levee at right angles to the embankment on each side. These cross levees have along their bases distributing ditches with gates on their lower sides, so arranged that water can be admitted into the compartment between the levees lying next below. Flooding is accomplished by admitting water in large quantities to a compartment at its upper end and allowing it to flow in a broad, shallow sheet to the lower end. Water not absorbed in thus passing through a check is collected at the upper base of the lower cross levee and is allowed to find its way back into the distributing canals for use at points below. Only land with a smooth surface and of very slight slope can be irrigated in this way. The system is better adapted for alfalfa fields than for grain land, because in the former the surface of the soil is more compact and the plants offer more resistance to the flowing water.

The following examples of irrigation, illustrating the duty of water, are in part taken from Mr. James D. Schuyler's report to the State engineer in 1880.[1] The latter ones are from unpublished data collected and prepared for the use of the State engineer in his final publication, which has not been issued.

In the following table the quantity of water used by some Chinese vegetable gardeners in 1879 from the Kern Island Canal, near Bakersfield, is noted. The data on which the table is based are reliable.

Quantity of water used by gardeners in 1879 from the Kern Island Canal, near Bakersfield.

Name of irrigator.	Area of land irrigated.	Total water used.	Average depth of water used on land.	Cost of water per acre.	Period of irrigation.
	Acres.	*Cubic feet.*	*Feet.*		
Sin Mon	30.0	5,320,800	4.07	$1.97	Dec., Feb. to June (incl.).
Ah Cow	.8	1,331,840	38.20	20.00	Feb., Mar. to June (incl.).
Ah Gee	50.0	6,375,600	3.00	1.42	Jan., Mar. to June (incl.).
Ah Song	3.2	2,751,200	19.70	10.00	Jan. to June (incl.).
Ah Lung	3.2	2,322,432	17.00	6.17	Feb. to June (incl.).
Sing Lee	10.0	1,668,880	3.80	1.92	Apr. to June (incl.).

The smaller of the gardens irrigated have a stream of 6 to 12 inches (0.12 to 0.24 second-foot) running continuously, day and night.

On secs. 1 and 2, T. 30 S., R. 27 E., 2 miles south and west of Bakersfield, along Panama Slough, where the land receives the percolation of several channels, natural and artificial, a field of 50 acres of alfalfa is irrigated in six days and nights with a stream equal to 1½ second-feet, and an orchard of 20 acres is irrigated in two days and one night with the same amount. The discharge would be equivalent to a depth of 0.36 and 0.37 foot, respectively, over the land irrigated. The soil is an alluvial loam. The orchard is irrigated once a month, and the alfalfa field once or twice a year, or more, when it is used as a pasture.

SE. ¼ sec. 30, 6½ miles south of Bakersfield, was irrigated first in 1878. Four acres can be irrigated in twenty-four hours with 7 second-feet. Allowing a loss of 1 second-foot in transit from canal to lands, this amount would be equal to a depth of 3 feet over the whole area. The soil is a sandy loam. Surface water is at a depth of 6 feet, rising to 3 feet after irrigation and subsiding again. The crops irrigated are wheat, barley, beans, sweet potatoes, alfalfa, and orchard and small fruits. The water used in 1878 cost $1.03 per acre, and in 1879 it cost 81 cents per acre.

On SW. ¼ sec. 31, 7½ miles south of Bakersfield, a first irrigation of 40 acres in May and June, 1879, was effected with 1,209,600 cubic feet of water, equivalent to a depth of 0.7 foot over the whole area. The land was thoroughly soaked in the spring by a break in the canal, and received the benefit of constant percolation. Cost per acre of the only

[1] Report of W. H. Hall, State Engineer of California, 1880, Part IV, App., p. 86 et seq.

irrigation given was 25 cents. The soil is a sandy loam containing decayed vegetable matter. Crops, cereals.

On sec. 32, 7½ miles south of Bakersfield, from July 23 to 29, inclusive, six days, 40 acres were thoroughly saturated with a discharge of 7.73 second-feet, equivalent to a depth of 2.3 feet over the whole area. The land had been irrigated but once before this season—the first week of May. It was dry to a depth of 6 inches, while surface water stood at a depth of 3.75 feet below surface. The land was first irrigated in the spring of 1878, when surface water stood at a depth of 17.5 feet. After first irrigation it rose to 12 feet; after first irrigation in 1879 it rose to 3.75 feet, where it remains. The soil is an alluvial sandy loam, mixed with partially decayed tule roots to a depth of 17 feet, and underlain by a stratum of clay 12 to 14 inches thick. The crops are wheat, barley, alfalfa, and corn. The average number of irrigations during the season is about one and a half. The average cost of water per acre is 70 cents. The average cost of labor (Chinese) per irrigation is 8 to 10 cents. A part of the land is irrigated by the check system, and a part by the small ditch or wild flooding system.

On sec. 5, T. 31 S., R. 28 E., 8½ miles from Bakersfield, adjoining the last-named section, with similar soil, and cultivated the same length of time, a record was kept of the quantity of water used for the second irrigation of a tract of 150 acres of corn. The total discharge in twenty-one days was 16,004,736 cubic feet, sufficient to have covered the land to a depth of 2.45 feet. The land had been irrigated in February or March for wheat, but it was so late that only weeds sprouted. In June the land was irrigated again to prepare it for corn, and the last irrigation noted above was from July 23 to August 12. The total cost of labor employed for the last irrigation of corn was $80.50, or 53.67 cents per acre. The total cost for water and labor was $1.20 per acre. The total cost of water used on the section during the season for 350 acres of wheat and 150 acres of corn was $452.32, or 90.5 cents per acre.

On sec. 7, T. 31 S., R. 28 E., the first irrigation of 50 acres of corn (the land having been wet before plowing in May) was accomplished in ten days—July 21 to 30—with an average discharge of 7.2 second-feet, equivalent to a depth of 2.86 feet over the whole area. The total cost for water was 31 cents per acre. The total cost of water for the season for irrigation of 90 acres of wheat and barley, 50 acres of corn, and 70 acres of alfalfa was 55 cents per acre. The soil was in part black, stiff loam, almost adobe in texture, in part loam mixed with sand, and in part coarse sand underlain by quicksand. Most of the land under cultivation was irrigated this year for the first time. The ranch could nearly all be subirrigated, but the owner preferred the small ditch system. He thinks that next year his land will absorb not more than one-half the water it has this year.

On secs. 21, 28, and 33, T. 31 S., R. 28 E., and sec. 4, T. 32 S., R. 28 E., 12 miles from Bakersfield, in the vicinity of Kern Lake, 800 acres

of wheat, corn, and alfalfa were irrigated once, 250 acres irrigated twice, and 100 acres three times. The entire acreage required a total of 66,450,000 cubic feet of water during the season—equivalent to a depth of 1.33 feet at each irrigation. The average cost of water was 50 cents per acre for the season. The soil is a stiff, black loam, 1 to 2½ feet thick, underlain by yellow clay 2 to 4 feet thick, beneath which surface water is abundant in a stratum of sand. Moisture is also found above the clay, maintained by drainage of lands above.

On sec. 4, T. 31 S., R. 27 E., in one experiment 3⅓ acres, prepared with care, leveled, and checked with proper levees, were covered in fifteen hours with an average discharge of 2⅔ second-feet, equivalent to a depth of 0.87 foot over the whole area. The land lies adjacent to Panama Slough, from which it receives moisture by percolation. The soil is a sandy loam of considerable depth. The surface water is 8 feet below the surface. The land had been irrigated four or five years.

At Livermore Ranch (Greenfields), secs. 18, 20, 29, 30, 31, 32, T. 31 S., R. 29 E., and sec. 5, T. 32 S., R. 29 E., the average number of waterings required is 1½—one general irrigation and a second irrigation on the drier spots. The average cost per acre for labor of irrigation is 12 to 15 cents. The average cost for the season for labor and water is $1.50 per acre. The water was shut off from March 17 till May 15, causing the failure of 300 acres of barley and 600 acres of wheat that had been sown. No data could be obtained as to the quantity of water used per acre. The ranch being at the terminus of the main canal and the central branch, the supply fluctuates according to the demands from the lands above.

Mr. Schuyler says: "These examples are all taken from lands requiring comparatively little water, as they are all subject to percolation from numerous sources. Most of the lands referred to are irrigated from the Kern Island Canal. This being the only canal in the county from which water is sold by measurement, the data afforded regarding the cost of irrigation and the quantity consumed are more definite and reliable than any that could be obtained elsewhere."

A few other examples may be given as approximately correct to illustrate the thirstiness of other classes of soils.

On Bellevue Ranch, T. 30 S., R. 27 E., no exact data as to volume of water used could be obtained. The average number of irrigations required for cereals is two to three, one being sometimes sufficient in seasons of favorable rainfall. For alfalfa three or four irrigations are generally needed; for corn two are sufficient. The soil is sandy, with streaks of heavy loam marking the course of old sloughs.

On McClung Ranch, secs. 3, 4, and 5, T. 30 S., R. 26 E., and sec. 1 in township adjoining, the first year of irrigation (1874) a ditch, described as "12 feet wide on bottom, 2 feet deep, with a good average flow," was discharged for seven months upon 100 acres before the land was saturated. If this be true, such a ditch, with side slopes 1 to 1 and

grade of, say, 2 feet per mile, would have discharged enough water in that time to cover the land 166 feet deep. The water was, of course, not confined to the immediate neighborhood of the tract upon which it was discharged, but spread for miles in underground channels, filling up the loose porous soil to a depth of several feet. The average head of water which one man can conveniently handle in irrigating on the McClung Ranch is what will pass through a gate 4 feet wide with a depth of overfall of about 1 foot, equivalent to about 13 second-feet, and with this from 1 to 6 acres per day (of twelve hours) can be irrigated. This discharge is sufficient to cover the land from 2 to 13 feet deep. The land has been irrigated from three to four years, and absorbs a trifle less each year; but if irrigation be suspended for one season the surface moisture drains away, and the following year much more would be required than would have sufficed the previous year. This is the case, to a greater or less extent, in all parts of the valley of Kern River. On the lands cited in this example one thorough soaking is sufficient to produce a crop of cereals, with enough rainfall to sprout the grain. With no rain two irrigations are required—one to prepare the land, the other to mature the crop. Alfalfa requires three to four waterings through the season to maintain a vigorous growth. The soil is a coarse sand and sandy loam of great depth.

In sec. 13, T. 29 S., R. 27 E., on a strip of bottom land between the McCord Canal and Calloway Slough, 80 acres of alfalfa have been irrigated in four days and nights with a discharge of about 6 second-feet, sufficient to have covered the ground to a depth of 0.6 foot. The land had been irrigated for two or three years. The soil is an alluvial loam having an elevation of but 5 or 6 feet above the river, and receiving constant moisture from below by percolation. The crop was irrigated twice during the season prior to August 1.

On sec. 14, T. 29 S., R. 27 E., with a discharge equal to about 2 second-feet 2 acres of corn can be covered in a day of twelve hours, equivalent to a depth of about 2 feet over the whole area. This example was given as the fourth and last irrigation of the tract in the season, the land having been wet once before seeding and three times after. The land had been irrigated several years. The soil is a brown sandy loam 1 to 6 feet deep, underlain by hardpan not wholly impervious.

On sec. 8, T. 29 S., R. 27 E., alfalfa is said to require irrigation twice a month. Wheat is irrigated once before and twice after planting. Corn requires five irrigations, the first of which is given before seeding, in May, the last in the latter part of July. The soil is a sandy loam 2 feet deep, underlain by 2 feet of yellow hardpan. No data as to quantity of water required at each irrigation were obtained.

On sec. 27, T. 28 S., R. 26 E., the first irrigation was in 1879. Wheat required three or four irrigations, one prior to sowing. The land was irrigated by the check system, by which two men could water 160 acres in four days, at a cost of about 10 cents per acre per irrigation for

labor. The soil is similar in character to that cited in the foregoing example.

At Poso Ranch, sec. 9, T. 27 S., R. 25 E., a test was attempted to ascertain, if possible, the quantity of water absorbed by the desert lands on the plains north of Kern River, now supplied by the Calloway Canal. A check containing 3¾ acres was prepared and water was admitted in as great quantity as was expedient for the safety of the newly built banks about the gates. An hourly record of the head was kept, the discharge being from 4 to 9 second-feet. Eleven hours were required to fill the check sufficiently to barely cover the highest ground, when the water was shut off. Next morning all the water had soaked away. The quantity discharged was sufficient to have covered the whole area to a depth of 1.75 feet. A portion of the area doubtless absorbed five times as much as the higher spots, as the percolation seemed to be entirely downward, and not in a lateral direction. Three weeks later the check was filled in four hours and twelve minutes, with an average discharge of 13.35 second-feet, the ground being covered to an average depth of 1.25 feet. Some time between these two experiments the land was flooded by the breaking of a check above. The total quantity absorbed by the three waterings was probably not less than 4 to 5 feet. The soil is a brown sandy loam, of unknown depth, but probably greater than 20 feet to hardpan.

All of the above examples, illustrating at once the practice of irrigation and the amount of water required, are the result of inquiries and experiments made in 1879. To these the following can now be added.

On sec. 30, T. 30 S., R. 28 E., in August, 1881, water from the Kern Island Canal was used for five days to the extent of 3.63 second-feet for the irrigation of 30 acres of corn. The amount of water was equivalent to 1.21 feet over the entire area. The water was applied by the furrow system of irrigation. The soil is very variable, generally light and loamy. Its character ranges from pure sand to black adobe. Soil water is at a depth of 8 or 9 feet.

On the same section as the last, 60 to 70 acres of wheat were irrigated by flooding in checks lying between contour lines. The surface of the ground is smooth but not level. Water was used for eleven days in December, January, and February, at the rate of 3.61 second-feet, equivalent to a depth of 1.21 feet over the whole surface. It was again used for eight days in March, at the rate of 3.26 second-feet, equivalent to a depth of 0.97 feet over the entire surface. The ground received another irrigation between April 1 to 5, four days in all; water was used at the rate of 5.20 second-feet, and the equivalent average depth of water over the entire surface was 1.37 feet. The whole amount of water consumed in the irrigation of the wheat was therefore equivalent to an average depth of 4.18 feet of water over all. Alfalfa was irrigated on the same section to the extent of 50 to 60 acres. The water used for it prior to the end of May, 1882, was 5.20 second-feet for fourteen days in

March, and 7.36 second-feet for fifteen days in May. The amount of water which the alfalfa field received in these two irrigations was equivalent to a depth of 6.61 feet. It was proposed to give it, and it probably received, two more irrigations subsequent to the two here noted.

Sec. 31, T. 30 S., R. 28 E., has a loamy soil which does not crack or bake in drying, contains a small excess of alkali, and ranges in texture from sand to black adobe. In 1881 wheat to the extent of 125 acres was irrigated by flooding in checks. The surface of the ground is smooth but not level. The ground was wet before plowing in January. The amount of water it received at that time was equivalent to a layer 5.01 feet thick. It received a subsequent irrigation equivalent to a depth of 0.69 foot of water. The total average depth of water delivered to the land was therefore 5.70 feet.

On the same section, in 1882, a wheat field of 350 acres was supplied with water for sixteen days in the first part of January. Water was used at the rate of 3.26 second-feet, equivalent to an average depth of 0.30 foot. It received water again, at the rate of 7.41 second-feet, from April 1 for seventeen days, equivalent to 0.76 foot in depth over the whole area. For fourteen days, from April 25 to May 8, it again received water, at the rate of 8.60 second-feet, equivalent to a depth of 0.66 foot over the whole area. The aggregate average depth of water received by this whole tract in 1882 was therefore 1.72 feet.

On sec. 6, T. 31 S., R. 28 E., having soil of the same character as that described above for sec. 31, 120 acres of corn land were irrigated, from April 18 to 24, in 1882. This irrigation was preparatory to the planting, and was equivalent to a depth of 0.78 foot over the whole surface of the land. The corn received one more irrigation.

On sec. 32, T. 30 S., R. 28 E., whose soil is mostly a sandy loam, but ranges from pure sand to a dark vegetable loam, 130 acres of wheat were irrigated in March and April, 1881. The head of water used was 9.91 second-feet. The depth to which it would have covered the ground averaged 2.34 feet. Ground water is at about 17 feet below the surface.

On the same section, in May, June, and July, 1881, 80 acres of corn received water to the extent of an average depth over all of 6.35 feet. The head of water was 9.91 second-feet. On the same section a 6-acre orchard was irrigated in August and September, 1881, and received water enough to cover the 6 acres 4.53 feet deep. The water used was 4.56 second-feet. On the same section, in March, 1882, an old alfalfa field of 100 acres was irrigated and absorbed water equivalent to a depth of 2.52 feet. The head of water used was 12.10 second-feet. On the same section, in March, 1882. newly sown alfalfa was irrigated; its area was 120 acres. It received water at the rate of 12.10 second-feet. The total amount of water it received was equivalent to a depth of 2.52 feet over the whole area. It was again irrigated in May, receiving 8.60

second-feet for eight days, or sufficient water to cover it 0.98 foot deep. It was proposed to give the newly sown alfalfa one more irrigation in 1882.

On sec. 7, T. 31 S., R. 28 E., whose soil varies from a light sandy loam to a black sandy vegetable mold, with ground water at from 4 to 10 feet below the surface, 300 acres were sown to wheat in 1882; alfalfa was sown with the wheat. The ground was not irrigated before sowing. The irrigation of this tract commenced on February 25 and was completed on April 6; water was used for forty-one days at the rate of 8.21 second-feet. The total amount consumed in irrigating the 300 acres was equivalent to a layer 2.22 feet thick over all. The wheat did not require any further irrigation. The young alfalfa was irrigated again after the wheat had been harvested.

IRRIGATION FROM POSO CREEK.

Poso Creek is a small foothill stream just northward from Kern River, which flows for several months each year. Its drainage basin has an area of about 289 square miles. The creek has not been used to any considerable extent for irrigation, because there is but little land that can be commanded with its water except at considerable expense, and because its brief irregular flow did not seem to justify works to benefit large sections. It was not, therefore, until the irrigation-district law went into effect that a combination of interests led to the projection and partial execution of works of considerable magnitude. Several small private ditches were in use before the organization of the Poso irrigation district, but no complete list of these is available. One of them is the Purcell Ditch, which takes water from the south side of Poso Creek, about 8 miles above Poso. The ditch was made 12 feet wide and 2 feet deep, and was in use in 1885 for the irrigation of about 400 acres of alfalfa, immediately below the head of the ditch and adjacent to the creek. Another ditch, on the south side of the creek, is the Creasey Ditch, constructed in 1885 for the irrigation of 300 acres of land about 4 miles above Poso. The head of the ditch is about 2 miles below the head of the Purcell Ditch. It was made 16 feet wide on the bottom. The Rhymes and Hughes ditches are small ones, somewhere in the foothill section drained by the creek, concerning which nothing definite is known except that they were in use for many years.

POSO IRRIGATION DISTRICT.

This district was organized in 1888. Its bond issue is $500,000. It has an area of about 40,000 acres, located to the north of Poso Creek, at the western base of the Sierra Nevada foothills, in Kern County. The contemplated works for the irrigation of the district are far advanced, though not yet completed. Much work on them was done by day's labor before it was decided to be advantageous to let contracts.

Water for the district lands is to be obtained from a system of reservoirs in the drainage basin of Poso Creek, which are to supplement the creek's natural flow. The first reservoir, now constructed, is formed by means of an earthwork dam to be raised to a maximum height of 70 feet, but now only half finished. Its capacity when completed will be about 7,000 acre-feet. From it water flows in the channel of Poso Creek about 7 or 8 miles to a point where it is diverted into a flume by means of a granite dam, whose greatest height is about 16 feet. The flume shown in Pl. XIV, *A* and *B*, is about 3 miles long and delivers its water into an apparently well-constructed hillside ditch which has a length of about 30 miles before reaching the district. Two other flumes are in use on the canal line to carry the water over deep ravines. The flumes have a width of 8 feet and are planned to carry water 4 feet deep. Water was sent through the canal for the first time this season, but only for the purpose of testing the work. This upper district canal is supplemented by a lower canal which leaves the creek about 10 miles above Famosa and commands the western portion of the district. This lower canal is in service, but irrigation is extending very slowly.

IRRIGATION FROM DEER CREEK.

Deer Creek is a small stream draining about 110 square miles of Sierra Nevada foothill lands lying southward from the Tule River basin. It flows into San Joaquin Valley during several months of the year; rarely, however, as late as July. Its water ordinarily sinks within 10 or 12 miles of the foothills, but occasional freshets have sent it as far as Tulare Lake. The summer flow of the creek, which is very small, does not reach the San Joaquin Valley lands.

Winfield Ditch.—This is a small ditch on the south side of Deer Creek, having its head about 4 miles above the point where the creek breaks out upon the main valley plain. It was constructed in 1858, is between 3 and 4 miles long and 3 to 4 feet wide, and supplies water to several hundred acres of creek bottoms. It has been in use continuously since its construction. The entire low-water flow of the creek is taken into the ditch.

Carothers Ditch.—The head of this ditch is on the north side of Deer Creek, about a mile above the point where the creek reaches the border of San Joaquin Valley. It was constructed in 1885, but takes its name from an older ditch (constructed in 1868) which had for many years been out of service. It has a westerly course, and is about 5 miles long and 4 feet wide on the bottom.

Deer Creek Consolidated Ditch (*Sausalito Ditch*).—This is the principal irrigation work on Deer Creek. The head of the ditch is on the south side of Deer Creek, about 12 miles in a direct line above Belleville and about 3 miles below the head of Carothers Ditch. The ditch is carried

A HEAD FLUME, POSO IRRIGATION DISTRICT

B. HEAD FLUME, POSO IRRIGATION DISTRICT

along the south side of Deer Creek, close to the creek channel, for a distance of nearly 8 miles; thence its course is diagonally across the creek bed to its north side. From this point the course of the ditch is westerly and southwesterly, in a number of branches, which deliver water to lands lying to the east and northeast of Belleville. The crossing of the sandy bed of Deer Creek is effected between embankments of sand, which are sure of destruction during freshets, but which are quickly restored. The lower portion of this ditch system was constructed in 1875 and 1876. Two sets of farmers commenced operations independently, but soon found it advantageous to unite their interests and construct a ditch in common. It was soon found necessary to substitute an artificial channel on firm ground for the porous creek bed from the foothills to the head of the original ditch, and this led to the construction of the upper section of the ditch in 1878. The main ditch has somewhat irregular dimensions. Its bed width is generally about 10 feet. Its capacity has been estimated at 40 second-feet. The capacity of the lower section of the ditch, on the north side of the creek, is about 30 second-feet. The cost of this irrigation system, which furnishes water to 3,000 acres of land, was about $20,000.

When the consolidation of interests by those desiring to use water near Belleville was effected, it was determined to establish water rights that should become appurtenant to specified tracts of land. This plan could not be adhered to, however, owing to insufficiency of the water supply from the creek, which made it impossible to deliver water to many of the tracts westward from Belleville for which water was wanted. It was found necessary to confine the delivery of water to consumers near and above (east of) Belleville, and these have become the stockholders in the company which owns and manages the ditch.

During the irrigating season (generally November to the end of June) a ditch superintendent is in charge of water distribution. Water is delivered to the several branches in proportion to the number of shares of stock for which each is to receive water. As soon as the water becomes insufficient to meet the demands of irrigators the ordinary system of using it in rotation is adopted. Eight hours is usually fixed as the time of a run per share. No water is sold, and all expenses are assessed upon the stockholders. Management and repairs cost about $1,000 per annum. About one-third of the area irrigated is alfalfa; the rest is orchard, vineyard, summer crops, and some grain. Irrigation is accomplished by flooding in small rectangular checks. The preparation of the ground to receive water was inexpensive, its original surface having been very smooth. The soil is a sandy loam. At about 3 feet below the surface is a stratum sufficiently hard to be called hardpan. As usual in irrigated districts on the plains, irrigation has produced a permanent effect upon the elevation of ground water. This was originally found at a depth of 17 feet below the surface; it is now at 9 to 12 feet.

TULE RIVER.

HYDROGRAPHY.

Tule River enters San Joaquin Valley at Porterville, with a drainage area above that point of 437 square miles. The river has a perennial flow throughout its mountain and foothill portions, but not at points below Porterville, near where the last remnant of its water during very low stages sinks into its sandy bed. During the months of May and June the flow of the river, as estimated for the six years, 1878 to 1884, was over 1,000 second-feet. Its mean flow for that entire period was about 450 second-feet. From November to January the mean flow was 130 second-feet. It was 636 second-feet from February to April, 941 second-feet from May to July, and 139 second-feet from August to October.[1]

Below Porterville this water flows in several channels, one of which, Porter Slough, has its head on the north side of Tule River, about 3 miles above Porterville. The water not in this slough remains in the main channel for about 10 miles, then separates into a network of channels having a general westerly course, and is finally delivered into Tulare Lake. The main stream crosses the Southern Pacific Railroad about 2½ miles north of Tipton. Water rarely flows in this part of the river more than four months of the year.

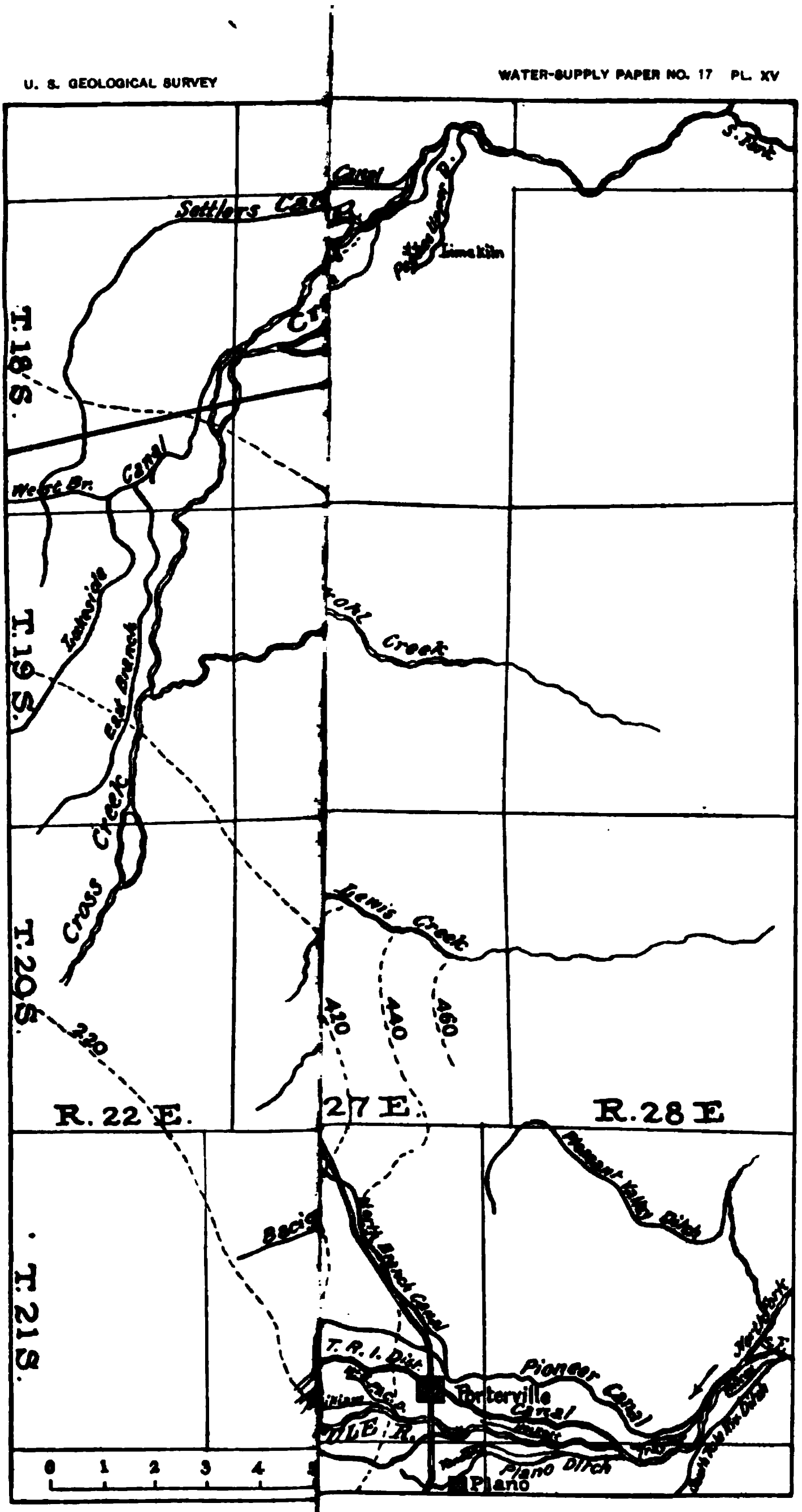
The Tule River channels are barely of sufficient capacity to pass ordinary freshets. This is particularly noticeable westward from Woodville on all the many channels into which the river is subdivided. The resulting bank-land inundations are of considerable extent and are an important supplement to artificial irrigation. The ready overbank escape of the freshet waters of the river and the very smooth surface of the delta lands greatly facilitate the diversion of water into ditches and canals, which have become very numerous. Many of these are, however, mere cuts into the bank, into which water flows when the river is high and which become dry soon after the river recedes from its highest stage.

Where there are so many small, relatively unimportant diversions as from the several channels of Tule River, a minute description of each work will not be attempted, and in many cases a mere mention of name, general position, and time of first use must suffice.

CANALS AND DITCHES.

South Tule River Ditch.—This (sometimes called Campbell Ditch) is the uppermost ditch on the south side of Tule River, though by no means the first in time of construction. The diversion of water from the river is made at the head of an older ditch, known as the Wilcox, at a point about 8 miles above Porterville. The ditch skirts the base

[1] California Physical Data and Statistics, Wm. Ham. Hall, State Engineer, pp. 458 and 476.


Settlers Canal
Lime kiln
T.18 S.
West Side Canal
T.19 S.
Eastside
East Branch
Cross Creek
Oak Creek
T.20 S.
Lewis Creek
420
440
460
R. 22 E.
27 E.
R. 28 E
Beck
North Branch Canal
Pleasant Valley Ditch
T.21 S.
T. R. I. Dist.
Porterville
Pioneer Canal
Canal
Tule R.
Plano Ditch
Plano
0 1 2 3 4

of the hills, commanding a narrow strip of valley land which lies between the hills and the river. It is about 6 feet wide on the bottom, and has irrigated but a few acres. Its construction was commenced in 1879.

Wilcox Ditch.—The diversion of water into the Wilcox and South Tule River ditches is accomplished by means of an inexpensive wing dam of cobbles and brushwork. One channel in common is utilized for the water of both ditches for about a quarter of a mile. The Wilcox Ditch lies between the South Tule River Ditch and the river. It was constructed about 1855 for the irrigation of a small tract of land 2 miles below its head. The ditch is about 3 feet wide on the bottom.

Plano Ditch.—For the irrigation of lands in the vicinity of Plano, a small settlement on the south side of Tule River, directly opposite Porterville, a small ditch was constructed in 1863. It takes water from the south side of the river, about 3 miles in a direct line from Plano. It gradually withdraws from the river, crossing the river bottoms to the base of the hills, and skirts the base of "Sugarloaf" just to the east of Plano. Thence its course is southwesterly through Plano to a termination about 1 mile west of the village. The dimensions of the ditch are irregular; its capacity is about 16 second-feet. It supplies water to about 400 acres of orchard, alfalfa, and vegetables.

Vandalia Ditch.—This is another small ditch on the south side of Tule River. It takes water from the river a mile above Plano, has a capacity of about 3 second-feet, and irrigates about 100 acres. It was constructed in 1861.

Rose Ditch.—This is another of the small private ditches near Plano. Its head is several hundred yards below the head of the Vandalia Ditch. It was constructed in 1862. The land it irrigates was before that time supplied with water from a ditch known as the Somers Ditch, but the freshets of 1861–62 cut the irrigated district in two by the formation of a new channel for the river, and the Rose Ditch was built to supply water to a few acres of the original irrigated district left on the south side. It irrigates 10 to 20 acres.

Mitchell, Springer & Rose Ditch.—The head of this ditch was a short distance above the bridge on the road southward from Porterville. It was less than a mile long and about 4 feet wide on the bottom. The point at which water was taken from the river was frequently changed, and various tracts of land were irrigated with its water. It was one of the old-time ditches which now seems to have fallen into disuse. The extent of irrigation from it a few years ago was less than 20 acres.

South Side Tule River Canal.—This canal, which was for many years referred to as the "Big Ditch," and is also known as the "Poplar Canal," was constructed in 1875 by an organization of farmers whose lands were located on the main San Joaquin Valley plain, south of Tule River. The head of the canal is just above the bridge southward from Porterville. The canal regulator has been placed about a quarter

mile below the bridge. The ditch has a bed width of 20 feet, and is intended to carry water 2 to 3 feet deep. The course of the canal is westerly. It is about 11 miles long. In seasons of ordinary rainfall there is no trouble in keeping the canal well supplied with water during the spring months. At other times, and often when water is most needed, the supply is scant. The flow of the main canal is usually apportioned to one or more of the distributaries, or district ditches, as they are called, and the entire flow of each of these is used in turn by the irrigators. The length of time that an irrigator may use the water is determined by the number of shares of stock held by him.

The use of the canal has been interfered with considerably by litigation. Riparian land-owners have been successful in throwing legal obstacles into the way of water diversion for this canal, and court decisions against canal interests have been enforced to some extent. The area irrigated has, therefore, remained small—probably less than 1,000 acres. The cost of the canal was about $20,000, but under good management would have been less. Check weirs were placed in the

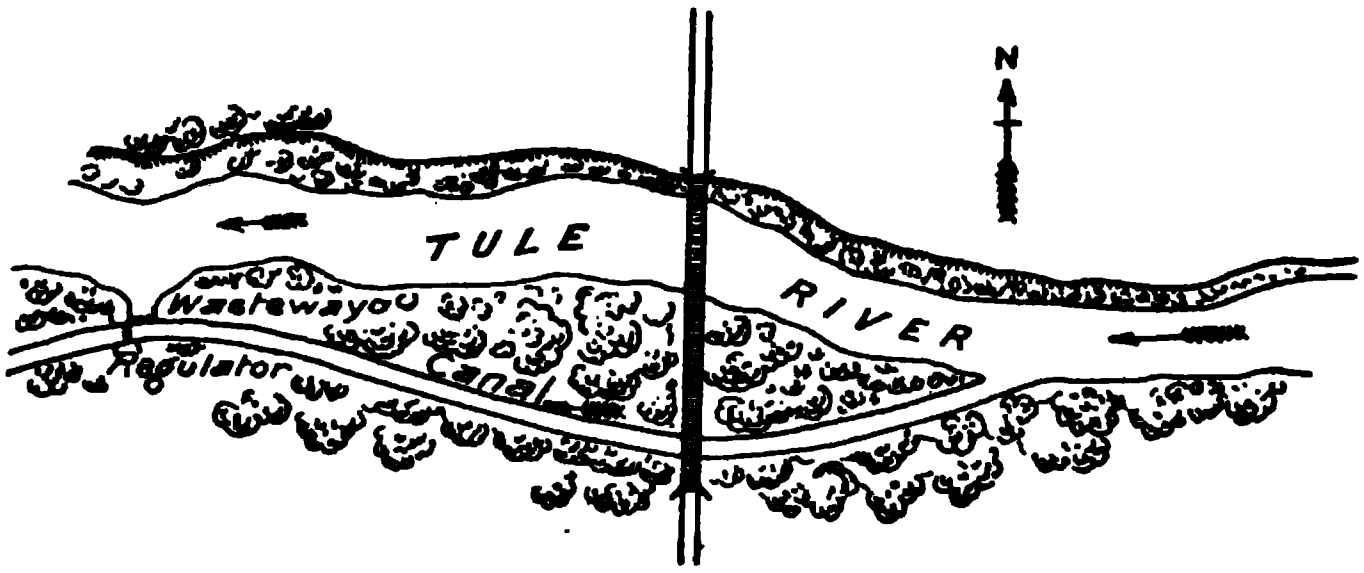


FIG. 14.—South Side Tule River Canal.

canal every half mile, but did not serve long. They were soon washed out of place. Their purpose was to prevent excessive erosion (the fall in the direction of the canal being about 15 feet per mile) and to facilitate diversion into branch ditches. After the first set of these structures was gone the expense of placing a weir in the main canal at the head of a distributary was thrown upon the owners of the latter, but the canal management reserved the right to approve the design and to supervise its construction. The original check weirs were of the flashboard type. The bays had a width of 4 feet. The timbers supporting the flashboards were inclined. The principal defect seems to have been the placing of the floor of the structure at, and not below, the grade height of canal bottom.

Fine Ditch.—The head of the Fine Ditch is about 3 miles below the head of the South Side Canal. It commands a district intermediate between Tule River and the lands irrigated with water from the South Side Canal. The ditch was built and is owned in common by a number of farmers, who apportion its water among themselves. It is about 7 miles long.

A REGULATOR AND WASTE WAY OF SOUTH SIDE TULE RIVER CANAL.

B. REGULATOR OF PIONEER CANAL, LOOKING UPSTREAM.

Callison Slough.—Callison Slough (Woods Central Ditch) is a high-water escapeway from the south side of Tule River, about 5 miles due west from Porterville. It was probably one of the many new channels formed by the freshets of 1861–62. Water enters the head of this slough under control of a regulator at the high stages of the river, and at lower stages the flow is increased by means of a temporary wing dam of sand, which is extended farther and farther upstream as the river falls. The flow of the slough has been under control for irrigation since 1878, in which year a company was organized for this purpose, under the name of the Woods Central Irrigating Ditch Company. The head gate was made 18 feet wide. About $1,560 was expended in converting the slough into a serviceable ditch. Several small distributing ditches have been constructed from the slough to the lands of irrigators, and about 1,000 acres represent the extent of annual actual wetting.

When the Tipton irrigation district was organized, in 1891, arrangements were made by its directors for the use of Callison Slough in com-

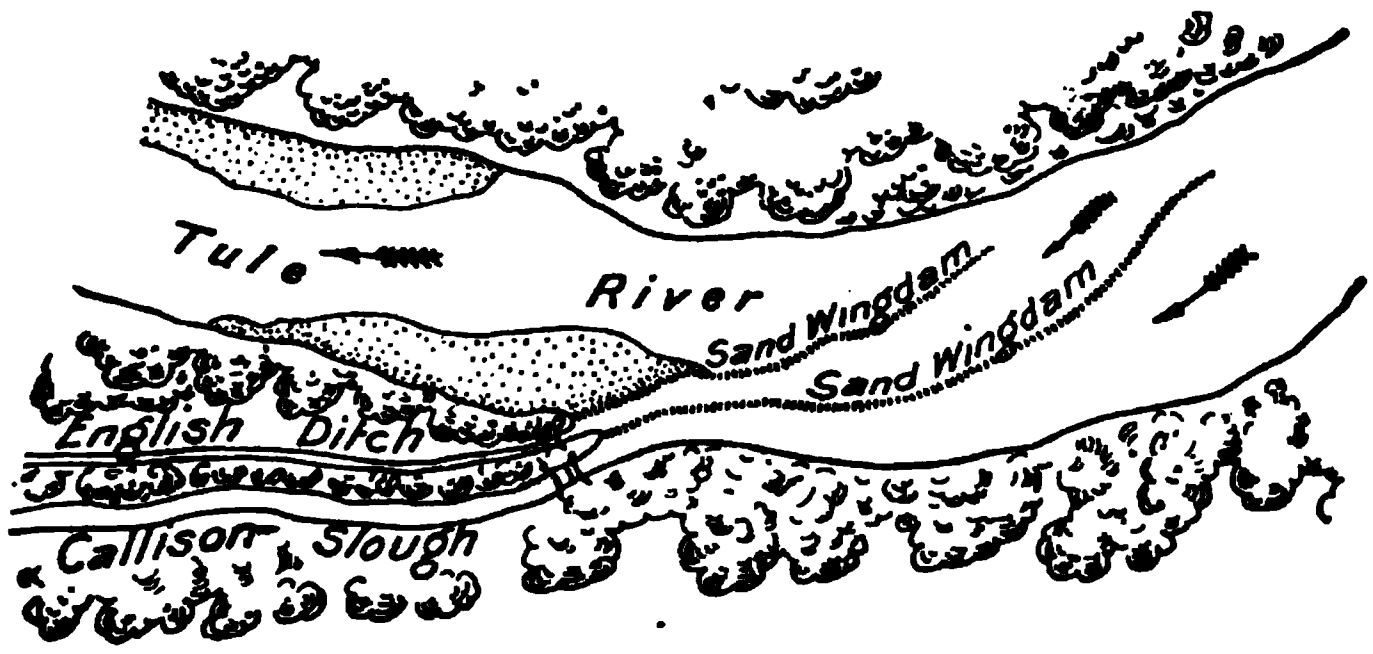


FIG. 15.—Head of Callison Slough and English Ditch.

mon with the Woods Central Irrigating Ditch Company. A new regulator was soon afterwards put into the head of the slough. It was made 30 feet wide, it being understood that 10 feet of its width was to serve the original users of slough water, and the other 20 feet the irrigation district. The district canal is out of service at the present time.

Old English Ditch.—The head of this ditch is immediately below the head of Callison Slough, and its water is used on several small farms between Callison Slough and the river. The ditch was constructed about 1869. It is about 8 feet wide on the bottom, 2 miles long, and annually irrigates between 100 and 200 acres. Whenever it is desirable to use water after the high stage of the river, a long temporary wing dam of sand is constructed at its head, just below, and almost parallel with, that at the head of Callison Slough.

Stockton Ditch.—This ditch takes its name from a small private ditch which was in use for a few years preceding 1871. It was built in 1874 by a company composed of eight farmers who desired a common source of supply. It leaves the south side of Tule River about midway

between Porterville and Woodville, and has a westerly course to the vicinity of the latter settlement. The ditch is about 6 miles long, and is 15 feet wide at its head. Water is ordinarily available for it from February to June. No restriction is placed upon the locality where each stockholder may use his water. The water is delivered in turn to each person entitled to its use, the time of a "run" per share of stock being fixed annually by the directors, usually at forty-eight or twenty-four hours per share. The lands irrigated by this ditch have in part been included in the Tule River irrigation district, and are to become dependent upon its works for their water supply.

Ball & Harris Ditch.—About one-half mile below the head of Stockton Ditch a small ditch, irrigating several hundred acres of land, leaves the river. It is known as the Ball & Harris Ditch (or the Markham, or Pierce & Markham, or Pierce, Markham & Booth Ditch). It was built about 1871, and is reported to have been in continuous use after 1874. The ditch is only 3 to 5 feet wide on the bottom. Its regulator has a width of 6 feet. This is one of the ditches whose rights have been merged with those of the Tule River Irrigation Ditch Company.

Empire Ditch.—The head of this ditch (also called Pheil & Otto, Stover, or Lower Pioneer Ditch) is on the south side of Tule River, 3 miles east of Woodville, at a point known as the Forks of Tule River. Its course is westerly; it is 3 miles long and irrigates several hundred acres of land in the immediate vicinity of Woodville. Its width is 2 to 3 feet on the bottom, and its estimated capacity is about 5 second-feet. The lands served by this ditch are in part in the Tule River irrigation district.

Woodville Ditch.—This ditch has its intake on the south side of the river about 1½ miles northeast of Woodville. Its course is westerly; its length is about 7 miles, and its width in the upper sections about 10 feet on the bottom. The regulator has a width of 12 feet. The ditch was constructed in the years 1883 to 1885. It is one of the few ditches constructed and managed on the principle of proportional assessment of stockholders to meet those expenses only which are incurred on the ditch above the point where water is delivered to each irrigator. This is another of the small ditches whose rights have been merged with the Tule River Irrigation Ditch Company.

Tipton Ditch.—This ditch (also called Mitchell Ditch) was constructed for the irrigation of lands near Tipton. Its builders agreed to contribute to the cost of construction and maintenance of so much of the main ditch as was above the upper limits of their lands in proportion to their respective interests in the canal water. The construction of the ditch commenced in 1881, but it was not completed for several years. The head of this ditch is on the south side of Tule River, about 3½ miles northeast of Tipton. The ditch has a southwesterly course, is 6 to 7 miles long, about 20 feet wide near its head, and is planned to deliver a relatively large amount of water to the area dependent upon

it during the short period (about February 1 to June 15) when water is ordinarily available.

Janes Ditch.—This is a very small private ditch, the head of which is about a quarter mile below the head of Tipton Ditch. It follows the river bank, crossing Lone Oak Slough and South Tule River to a small tract of land irrigated with its water.

Lone Oak Slough.—This is a small high-water channel breaking out of the south side of Tule River due north from Tipton, about a half mile above the railroad crossing. It has a southwesterly course, and supplies water to several independent small distributaries known as the Hively, the Creech, and the Rogers Lower ditches. The flow of water in the slough is controlled by a regulator, put in about 1891.

Hively Ditch.—This is a small private ditch, about a mile long, receiving water from Lone Oak Slough just to the west of the railroad crossing.

Creech Ditch.—This is another small private ditch, about a mile long, leading from the south side of Lone Oak Slough.

Rogers Lower Ditch.—This ditch also receives water from Lone Oak Slough. It is a mile below the Creech Ditch, and is about 2 miles long.

The combined irrigation from Lone Oak Slough ditches probably does not exceed 200 acres.

Fancher Ditch.—Another of the Tule River ditches, owned in common by four or five irrigators, is the Fancher Ditch, which for several years prior to 1884 is reported to have received its water from the river at the point where Callison Slough unites with South Tule River. A weir was constructed in the river channel and the diversion was made from the slough channel. About 1884 it was found necessary to extend the ditch upstream about half a mile to a new head, where for some time water was admitted without control. The ditch has a southwesterly course, is about 2 miles long and 12 feet wide, and usually irrigates several hundred acres.

Finney Ditch.—On the north side of South Tule River, near the last-mentioned diversion, is a small private ditch, known as the Finney or Berry Ditch. Its head is a quarter of a mile below the head of Fancher Ditch. Water is there diverted into a small natural depression, in which it flows about half a mile to points where it is used by several irrigators. This ditch came into use in 1884.

Swall Ditch.—Another small private ditch, on the north side of South Tule River, is the Swall Ditch. Its use dates back to 1875. Its head is 2½ miles below the head of the river channel called South Tule River. It is about 2 miles long, and has a westerly course.

Gully Ditch.—This ditch receives water from the south side of the main channel of Tule River, 1½ miles below the head of South Tule River. It has a southwesterly course, is about 2½ miles long, and, in common with the Swall Ditch, supplies water to several hundred acres. It was constructed in 1875.

Swall & Wessling Ditch.—This is a small ditch on the south side of the main channel of Tule River, about a mile long, which connects this channel with a small natural water course. Its head is 3½ miles below the head of South Tule River. It has been in use since about 1884.

Great American Ditch.—Before the Tule River Indian Reservation, above Porterville, was thrown open to settlement the construction of a small hillside ditch for the irrigation of lands intermediate between the north-side hills and the river had been commenced. This ditch had its head on the west side of North Fork about 8 or 9 miles above Porterville, and was intended solely for the use of the Indians. This work was subsequently to have been completed by a corporation which seems to have been organized principally for speculative purposes. There is but little left of the enterprise except the name.

Pleasant Valley Ditch.—This is a diversion from the west side of North Fork of Tule River, about 2½ miles above its junction with Middle

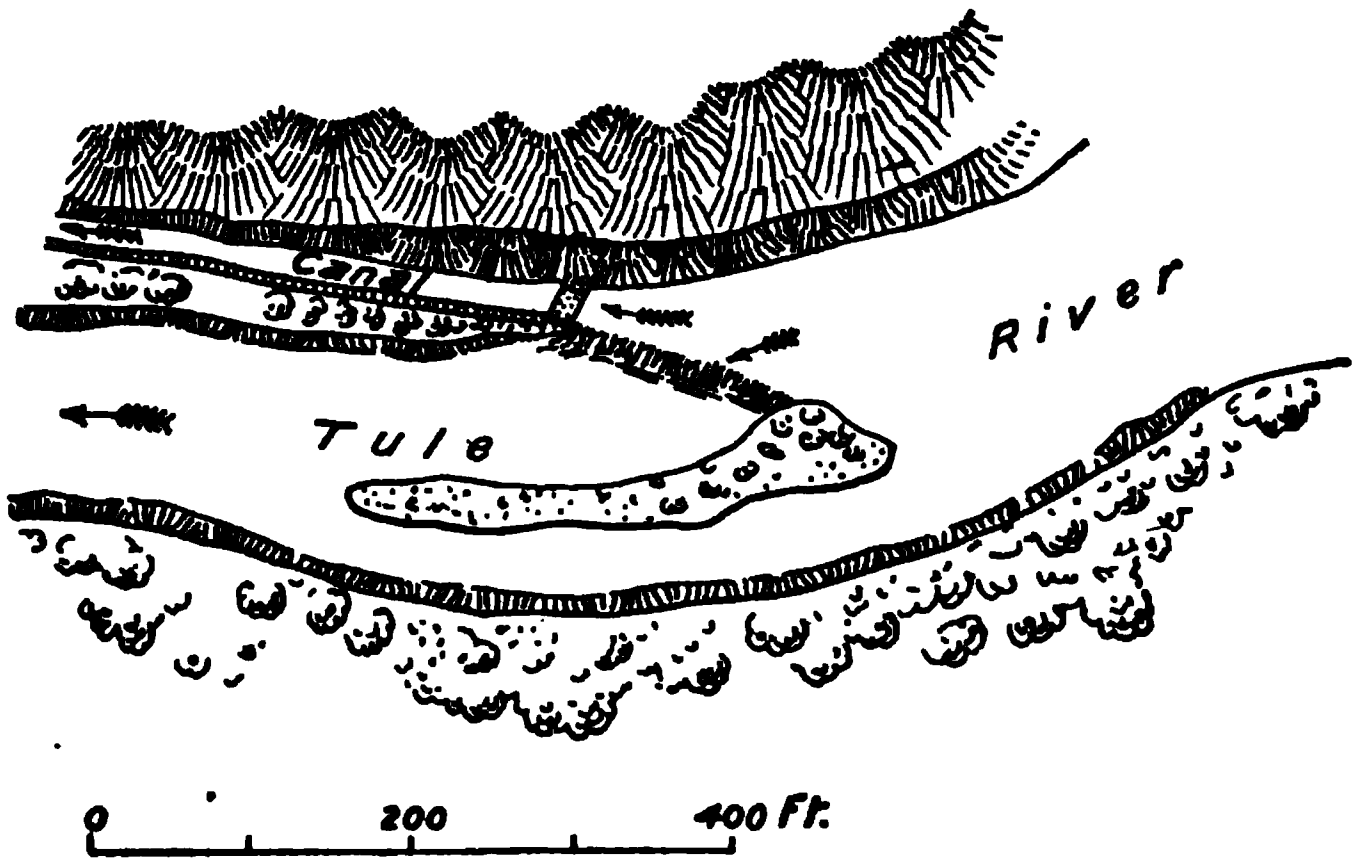


FIG. 16.—Head of Pioneer Canal.

Fork. The ditch has a southerly course for over 5 miles, thence a northwesterly course for 5 miles, and thence a southerly course for over 2 miles. It commands Pleasant Valley lands. Its bed width is about 6 feet for several miles, thence 4 feet. The ditch was constructed in 1889 by the Pleasant Valley Ditch Company, organized as a corporation the previous year by farmers requiring water for stock and irrigation purposes.

Pioneer Canal—This canal, controlled by the Tule River Pioneer Water Ditch Company, is the most important of the several irrigation works receiving water from Tule River. It was constructed and first came into use about 1867. Its head was then located three-quarters of a mile below the junction of North and South forks of Tule River. The freshets of 1877–78 destroyed the upper section of the canal and at the same time cut a high-water channel near the base of the hills at the northern border of the bottom lands. This new channel was at once utilized for

the canal water. A regulator was put in its head and has been maintained. The canal proper terminates at the flour mill at Porterville, to which it supplies power. Its course is along the base of the hills on the north side, and generally half a mile to 2 miles from the river. The bottom lands thus commanded above Porterville are very productive. The canal has a length of about 7 to 8 miles. Its fall is somewhat irregular, generally 6 to 7 feet to the mile. Its bed width is 8 to 12 feet, and the depth of water carried 2 to 3 feet. Its regulator is of the box or culvert type. A loose-rock fill on top of the structure gives it weight to prevent its being undermined. Three vertically sliding gates control the inflow of water. The width of the regulator between side walls is 18 feet. The capacity claimed for the Pioneer Canal is 72 second-feet.

Before a reorganization of the canal company was effected, several years ago, the canal water was delivered to stockholders in proportion to the amount of stock owned by each. Stockholders were permitted to take their water at any convenient point through a suitable outlet gate, constructed and maintained by the user of the water taken. No water was sold by the canal company, and all expenses of management and repairs were assessed to the stockholders. The result of this system of operation was the union of interests by groups of irrigators, who then made a common diversion of water from the main ditch and built distributing ditches, which are managed much the same as independent ditches.

The most notable branch of this character was the Farmers Ditch. It received water from the Pioneer Canal at the mill, and, passing to the east and north of Porterville, had a course a little north of west, skirting the southern border of Old Tule River Swamp. Its length was about 12 miles. It was owned by an organization formed in 1875, ownership being represented in 12 shares. Each share of stock entitled its holder to a proportional interest in the canal down to a point where he diverted or intended to divert his water from the main canal. The company did not sell any water. Water was used from the canal in rotation, the duration of a run per share of water being mutually agreed upon.

The cost of construction was apportioned to each member in proportion to his interest in the canal. Each member bore a proportional part of all expenses incurred along the canal above the point at which he was to receive his water, and did not contribute toward the construction of the canal below that point. Expenses of maintenance and repairs were apportioned on the same basis to those actually using water. As the canal had a total length of 12 miles, and some of its water was used within 3 or 4 miles of its head, these expenses were about four times as great for the most distant irrigator as for the one nearest the head of the canal.

Farmers Ditch in its upper sections was also known as the Old State

Ditch, being one, or on the line of one, of the ditches that was intended to divert the flow of flood waters from the Old Tule River swamp lands, and which had been constructed with money from the State swamp-land fund. This ditch, in somewhat altered alignment, together with the North Branch of Pioneer Canal (which might also be called the North Side State Ditch), has become one of the principal distributaries of the reorganized Pioneer Canal Company.

Water is still delivered to stockholders in proportion to stock owned, but without actual measurement. A change is to be made at once, according to which water is to be sold to stockholders on the basis of 1 miner's inch per share of stock. The canal capacity, 50 second-feet, is equivalent to 3,600 miner's inches under 4-inch pressure, and there are 3,600 shares of stock in the corporation. The price to be charged for water is to be fixed at 5 cents per 24-hour miner's inch.

The area of citrus fruits dependent upon this canal for water has within the last few years rapidly grown to 1,000 acres. About 900 acres of other orchards are also irrigated by this canal. The orchard lands for the most part lie to the north and east of Porterville.

The wetting of orchard land is generally accomplished by allowing small streams of water to flow in a number of furrows between rows of trees, usually four, and to harrow the surface as soon after the application of water as possible.

On the lower section of the Farmers branch of the canal alfalfa and grain are irrigated in rectangular checks. Land there is smooth surfaced and comparatively level, consequently the cost of preparation for irrigation is small. It is said to have been as low as 50 cents per acre for ditching and checking.

The value of water stock at the present time is said to range from $200 to $300 for stock entitling to water above the Porterville Mill, and $50 to $100 for stock entitling to water below the mill. This difference in price is due to the fact that most of the flow of the canal must be delivered at the mill for power purposes, and that water for diversion from the canal by irrigators above the mill is therefore limited.

Traylor Ditch.—This is a small private ditch having its head on the north side of Tule River half a mile below the head of the Pioneer Canal. It has a course about midway between the larger ditch and the river, is about 2 miles long, and irrigates a few acres of river bottom land.

Porter Slough.—Porter Slough breaks through the north bank of Tule River about 4 miles above Porterville. It was made the principal channel of Tule River by the freshets of 1861–62, but within a few years contentions arose as to the apportionment of water to this channel and to that which afterwards became the main channel of the river. Obstructions placed in the head of Porter Slough were repeatedly removed by settlers along the slough. It is claimed that such obstructions, in part at least, caused the rapid enlargement of the other

channel of the river by the freshets of 1867–68, and that ever since that time some work at the head of Porter Slough is annually necessary to put water into it at ordinary stages of the river.

Since the construction of the works for the irrigation of lands in the Tule River irrigation district, water is turned into the head of Porter Slough through an artificial channel or cut 700 feet long, in the head of which a regulator is maintained. This regulator has a total width of 36 feet, divided into nine spaces, of which seven are separated from the other two by a longitudinal partition. The water passing through the larger portion of the gate is for the irrigation district, the rest is for the Hubbs & Miner Ditch, which formerly received its water through an independent head some miles below Porterville. The actual flooding of lands with water from the slough before its use by the Tule River irrigation district was not very extensive, but the presence of water in the channel accomplished much wetting of adjacent agricultural land.

Hockett Ditch.—This is one of the small ditches which was constructed immediately after the freshets of 1861–62 to replace Somers Ditch, which was destroyed by the high waters. Its head is on the north side of Tule River, about 1½ miles below the head of Porter Slough. It supplies water for several hundred acres of land between Porter Slough and the main channel of the river southward from Porterville. The Somers Ditch, whose water rights are claimed for the Hockett Ditch, is reported to have been constructed in 1858, and it is probable that some of its original owners had attempted to make diversions of water as early as 1854.

Wallace Ditch.—The head of the Wallace Ditch is immediately below that of the Vandalia Ditch. Although the diversion of water for this ditch is made on the south side of the river, it is at once carried over to the north side in a small flume, and its use is entirely on the north side. It is a small private ditch, occupying a position between the Hockett Ditch and the river and supplying water to a few acres in the same vicinity as Hockett Ditch.

McGee, Putnam & Caldwell Ditch.—This is another small north-side ditch, having its head about 1¼ miles below the bridge south of Porterville. It commands lands between the river and Porter Slough just west of those covered by Hockett and Wallace ditches. It is said that the use of water through this ditch commenced about 1863.

Gilliam Ditch.—This ditch leaves the river about a quarter mile below the McGee, Putnam & Caldwell Ditch. It is a small private ditch which is also known as the Gillis Ditch, or the Gilliam & McGee Ditch. It was probably constructed in 1862 and commands a portion of the district originally irrigated by the Somers Ditch.

Hubbs & Miner Ditch.—This is a north-side ditch supplying water to eight or ten farmers, whose interests in the ditch are represented by shares of stock. The head of the ditch was about 2 miles below the

Porterville road bridge until, in 1893, a combination with the Tule River irrigation district was effected, according to which a common head or new inlet from the river to Porter Slough was constructed. Of the water diverted from the river, the surplus not required by the irrigation district goes to the lands dependent upon the Hubbs & Miner Ditch for water.

Fulweiler and Hunsaker ditches.—The next north-side ditch has its head about 6 miles below Porterville. It is known as the Fulweiler Ditch. Its construction was commenced by an organized association of farmers, but work was soon abandoned. One of the owners subsequently commenced operations again, and was joined in 1884 by several other farmers. The ditch was about 1½ miles in length, having a northwesterly course to a point where a junction was effected with another small ditch, known as the Hunsaker Ditch, whose head is half a mile below the head of Fulweiler Ditch. The Hunsaker Ditch had a length of about 2 miles. Its central section was used in common by the two ditches—an arrangement effected to overcome right-of-way difficulties which were encountered by the owners of the Fulweiler Ditch. The Hunsaker Ditch was constructed in 1871. About 400 acres were irrigated from the two ditches. All of the lands served by the Hunsaker Ditch and part of those served by the Fulweiler Ditch are now in the Tule River irrigation district and are dependent upon its canals for water.

Pletts Ditch.—This is a small ditch receiving water only during high stages of the river. It has been in use since 1872, but has ordinarily irrigated only about 10 acres of alfalfa and orchard land. Its head is just below the country road leading northward from Porterville.

Thomas Ditch.—Less than a quarter of a mile below the head of the Pletts Ditch, also on the north side of Tule River, is the Thomas Ditch. It is also called the Walker Ditch. It was constructed about 1871 or 1872. Like other high-water diversions from Tule River, it has had no regulator at its head. The extent of actual flooding with its water has been about 25 acres. The lands it watered are now served by the Tule River irrigation district canals.

Elrod Ditch—This is one of the same class of small ditches just enumerated. It is a reconstruction of an older ditch which was known as the Lewis & Walker, about 2 miles below the Thomas Ditch. The original ditch came into use in 1871. The lands irrigated by it are now a part of the Tule River irrigation district.

Ray & Brown Ditch.—This was an insignificant ditch on the north side of the river about 5 miles east of Bayou, which affords water for the flooding of a few acres at flood stages of the river. Like the other small ditches named, it has been absorbed by the Tule River irrigation district.

M. M. Burnett Ditch.—This is a small high-water ditch from the north side of Tule River, a mile southeast of Tagus. It is about a mile long,

has a bed width of 5 feet, and cost about $100. It was constructed in 1886.

Bond Ditch.—This is a small ditch which carries water southwesterly three-fourths of a mile from a point on the north channel of Tule River at the head of Schoolhouse Branch. It unites with Rogers Ditch for the irrigation of the same lands. This ditch was constructed in 1871.

Rogers Upper Ditch.—This is a diversion from the north side of the Stadtmüller Branch of Tule River, made in 1880. It has a northwesterly course for nearly a mile, to its junction with the Bond Ditch. The two ditches belong to the same owners.

Rogers Middle Ditch.—This is a ditch from the lower end of the Schoolhouse Branch of North Tule River. It is a short ditch 6 feet wide, having a southerly course, and drops its water into a natural channel, whence it is again taken for the irrigation of several small tracts. It was constructed in 1880.

Klein Ditch.—This ditch was practically duplicated by the Rogers Middle Ditch. The diversion was made from the same point, but in a ditch located a few feet farther east, and the same natural channel was used to convey water about a mile to its place of use. The mention of the ditch is merely historical; it went out of use about 1880.

Lamarsna Ditch.—This is another of the very small high-water ditches which abound in the Tule River country. It was constructed in 1878 or 1879, to supply water to several farms lying between the main channels of Tule River about 3 miles southeastward from Bayou. It has been in actual use very little, and but a few acres of alfalfa have been dependent upon it for water.

Bacigalupi Ditch.—Southward from Bayou, on the north side of the main channel of Tule River, is another high-water ditch, which has been in use more or less since about 1882. It is a short private ditch which supplies water for use on several hundred acres of land.

Bacigalupi & Creighton Canal.—This canal was constructed, in part at least, in 1877. It is really a diversion from Elk Bayou, the southernmost delta channel of Kaweah River, but as Lower Elk Bayou may also be considered a Tule River channel, receiving water from Porter Slough and being the main channel of Old Tule River, it will not be out of place to enumerate this canal among the Tule River ditches, particularly as the flow of Main Tule River into the lower end of Elk Bayou is chiefly relied upon as a source of supply for this ditch. The head of the ditch is on the north side of the bayou, about a quarter of a mile above its junction with the main channel of Tule River. The canal has a northwesterly course for about 4 miles, thence a southwesterly course for a like distance to near the eastern margin of Tulare Lake. It was built primarily for the reclamation of land entered as a desert claim. The regulator built in the head of the canal was soon washed out of place and the upper end of the original canal was considerably enlarged by erosion. The upper part of the canal was originally about 8 feet wide

on the bottom, but a width of 12 feet on the bottom, with a water depth of 2 to 3 feet, is claimed for most of its course. So far as can be learned, there has been but little systematic irrigation in the territory commanded by this canal.

Tulare Lake Canal.—This canal, which was built in 1890, takes water from Tule River at a point 10 miles due west from Tipton. It has a bed width of 40 to 50 feet and a depth reported at 4 to 5 feet. It lies within the extreme high-water limit of Tulare Lake. Its course is due south and its length is 3 miles. It commands the lands westward to the present lake margin. Water is expected to be available in this canal from about February to July. It is reported to have supplied water this season to 7,000 acres of grain land. At the head of the canal structures of the ordinary open flashboard type are in use for the diversion and control of the water. The cost of the canal head works is said to have been $3,000, and the cost of the main canal and 10 to 15 miles of branch ditches, including the head works, was about $10,000.

TULE RIVER IRRIGATION DISTRICT.

In no portion of the State has the necessity for harmonizing conflicting claims to water and adequate control of its diversion and use been greater than on Kaweah and Tule rivers, and it is on these rivers that the successful operation of the irrigation-district system was to be anticipated. It seemed as though all irrigators could only gain, and none lose, by bringing the many small independent ditches under one management, as authorized by the district law. And, in fact, no difficulty was encountered in forming on Tule River two irrigation districts, both of which have constructed canal systems, but in both of which there is now much dissatisfaction with the operation of the law and with the results thus far achieved. Of course the disappointments and failures are, in part at least, due to the general depression of the farming industry; but with an increasing tax rate as a burden upon those who meet their district obligations, and with probable confiscations of the property of those who continue delinquent, the problem of district management becomes difficult of solution.

The Tule River irrigation district was organized in September, 1891. A bond issue of $90,000 was soon followed by a second of $10,000. The district has an area of about 22,000 acres—practically all the lands within or immediately adjacent to the delta of Tule River. The district has a greatest length in the direction of the river of 13 miles, its eastern limit being about 6 miles west of Porterville, and a breadth of about 4 miles. Some of the land within exterior boundaries has been excluded.

The entire bond issue has been expended in completing the canal system. The bonds could not be sold readily and were finally, through the hands of a nominal purchaser, turned over to the contractors, who carried on operations by hypothecating them. The canal system consists of a main water way to and into the district—Porter Slough—and

two principal laterals, one on each side of Tule River. At the head of Porter Slough a cut 700 feet long has been made from the river into the slough. In this cut a regulating gate 36 feet wide has been placed, which is intended to serve the irrigation-district canal as well as the Hubbs & Miner Ditch. Of its 9 bays or openings, 7 are for the district and 2 for the other ditch. After flowing in Porter Slough for 7 or 8 miles the district water is taken into a large canal whose head is 3 miles west of Porterville, and which has a westerly course for 2½ miles to a point near the north bank of Tule River. The water is there separated into two canals, of which one has a northerly course back to Porter Slough and the other drops its water into Tule River, from which it is again reclaimed half a mile below. Porter Slough is the main north-side lateral for 6 or 7 miles; thence an artificial canal continues westward to near the western limit of the district. The south-side main lateral has a course almost due west for 11 to 12 miles, holding a position within one-half mile to a mile of the south boundary of the district. The older ditches within the district and smaller laterals complete the distributing system. The dropping of the south-branch water into Tule River is only a temporary arrangement, it being proposed to carry this water over the river in a flume.

Water is expected in the district canals from about March 1 to July 1. The irrigators are this season allowed to take water as they please, canal operation being blocked by litigation. It was at first proposed to meet operating expenses by levying an assessment upon the property of the district. This was done one season, and cost of operation was about $2,000. The following year, 1896, water was sold at 20 cents per irrigating head per hour, the head of water being understood to mean the amount which would pass over a clear overfall 4 feet long and 1 foot deep. This year, as already stated, water is taken by irrigators as they can get it.

TIPTON IRRIGATION DISTRICT.

The Tipton irrigation district is a second district dependent upon Tule River for its water supply, but its right to make a diversion extends only to the flood flow of the river. This district was organized in 1891. It contains 17,040 acres, located on the south side of Tule River, south of the lower portion of the Tule River irrigation district. A first issue of bonds of $50,000 was followed by a second to the amount of $20,000, but the second series has never been disposed of.

The district receives water through Callison Slough, the southernmost delta channel of Tule River. Arrangements were made with the Woods Central Irrigating Ditch Company whereby a regulating gate was to be placed and maintained for common use in the head of the slough. This was done. The gate was made 30 feet wide, 20 feet for the irrigation district, and 10 feet for the Woods Irrigating Ditch. The main

district canal was taken out of the slough about 2½ miles below its separation from the river. It reached the district by a course a little south of west, and four principal laterals were extended from it westward into the district.

The canal system cost the district $50,000 in bonds and an additional $11,000 represented by outstanding warrants. Here, as in other districts, bonds did not sell readily for cash at or above the limit prescribed by law, and here too the bulk of them went to the contractors of ditch work through a nominal purchaser.

The tax collector of the district has been temporarily enjoined from selling property for delinquent taxes. The residents of the districts do not seem able to pay the irrigation tax, which has been from 3 to over 4 per cent per annum. The operating expenses, including salaries of all officials and employees, were about $3,000 while the district was still in operation. Irrigation has therefore been extended very little, if any, under the district system, so that on the whole the outlook for this district is not encouraging.

METHODS OF IRRIGATION.

Irrigation from Tule River, with its many channels of slight depth, is very readily accomplished; so easily, in fact, that most of the farmers along its banks have in the past drawn its water through small ditches, generally owned in common by several irrigators. Small high-water ditches, frequently without head gates, are numerous, and there are but few irrigation works on a large scale. The dams in use to divert the water into the heads of the ditches are usually temporary structures of sand and brush. The only ones which are expected to withstand the freshets are those at canal heads above Porterville. The banks of Tule River are so low that but little cutting is required to carry water from the point of diversion away from the river banks. Only the lands near and above Plano and Porterville, and those along the Farmers' Canal, are favored with water for irrigation during more than the spring months.

Crops cultivated above Porterville are principally fruits, including citrus fruits, for which this section is famed, vegetables, and other summer crops. Below Porterville the most important crop irrigated is alfalfa. Most of the irrigated land near Porterville and Plano, where not in the river bottom, is a moderately dark loam. Water is applied to trees, vines, and vegetables in furrows run between rows. The slope of the ground in the region just indicated is ordinarily too great to permit of irrigation by any of the systems of flooding in checks, as elsewhere practiced. When irrigating in furrows, the water is delivered into a number of these at the same time from a small distributing ditch. The quantity of water admitted into each is so small that it does not cause erosion. As soon as the loose soil between furrows is thoroughly wet, irrigation is complete and water is turned off.

This system of irrigation was observed on a hillside about 1 mile east of Porterville. Water was diverted from a branch of the Pioneer Canal into a small distributary lying along the upper edge of the orchard to be irrigated. The amount used as an irrigating head was about half a second-foot. From the distributing ditch the water was diverted at regular intervals through small tubes of tin, stuck through short boards and placed temporarily into the side of the ditch; thence it found its way into the furrows. The grade of the furrows was about 1 foot in 20. The water was allowed to flow in thirty furrows at the same time and required the attention of one man. Constant attendance was required, but the labor was very light. This system of irrigation can be practiced to advantage only in the daytime. The furrows were about 3 feet apart; there were three furrows between each two rows of trees.

By means of this system of irrigation the ground was wet to a depth of 3 feet or more. After a few days the ground was well cultivated, in order to reduce the loss of water from the surface by evaporation. The soil of the tract thus irrigated is a light black loam, a dry bog, which becomes very soft and sticky when wet. The proprietor gave his vines and trees only one irrigation per annum. The average annual rainfall in this vicinity is about 11 inches. It is less at points farther west, being only about 7 inches along the central line of San Joaquin Valley at points opposite Porterville.

Lands along Tule River west of Porterville are for the most part level and have a smooth surface. Irrigation is generally accomplished by flooding in checks having an area of only a few acres each. Alfalfa is irrigated every four to six weeks while water is available; orchards and vineyards, once or twice a season, according to water supply; corn land, ordinarily once before seeding; and vegetables, almost continuously during the time water is available. Every ditch owner tries to keep water in his ditch as long as possible, because it is useful for stock purposes when not required for irrigation. The soil along the river is generally a sandy loam, usually resting on firm clay, called hardpan, found at a depth of 1 to 6 feet. Ground water near the river is about 14 feet; it is to some extent affected by the flow of water in the river and in ditches and its use in irrigation; but the time between irrigation periods is so long that the water table has not been permanently raised in consequence of irrigation. Irrigation has produced no marked changes in the character of the soil, though it is occasionally claimed to have been the cause of an increase of alkali at the surface of some of the lands irrigated. Fevers are, and always have been, prevalent to some degree along Tule River, and it is not possible from the limited data collected to determine to what extent the healthfulness of the country has been affected by the practice of irrigation.

Private ownership of ditches has been the rule on Tule River. The sale and measurement of water is now, however, about to become

an established fact on the Pioneer Canal, and has already been introduced in the Tule River irrigation district; but it practically amounts only to systematizing water distribution, compelling economic use, and putting the burden of canal maintenance upon the irrigator alone, the sale being restricted either to holders of canal stock or to taxpayers in a district.

PUMP IRRIGATION AT LINDSAY.

The water development by means of artesian wells in San Joaquin Valley is a subject of considerable interest, but can not be dealt with fully in this paper, owing to lack of detailed information concerning recent developments. But the use of water secured by pumping from a subsurface source has been so successful, in at least one portion of the field under consideration, that a brief reference to it will not be out of place.

Lindsay is a new settlement on the east-side valley plain, about 10 miles northwest of Porterville. It was at first proposed to bring water into that locality from Kaweah River, but before the difficulties in the way of canal construction were overcome it was found that a layer of sand at about 60 to 65 feet below the surface afforded a fair supply of water. Centrifugal pumps have been brought into service to develop this water supply. The pumps are placed in pits about 30 feet deep, near the surface of the ground water, and water is delivered by them through pipes to the place of use. Both steam and gasoline engines are in use to supply power. The irrigation is confined almost exclusively to citrus fruits, the cultivation of which commenced in this locality about five years ago. The water surface in the wells is lowered during pumping from 10 to 27 feet, according to pump capacity. The total height water is raised, including friction in pipes, is said to exceed in some cases 70 feet. One irrigator, with 2¼ cords of oak wood at $4 a cord, and one pump, claims to be able to irrigate from 20 to 25 acres of orchard land per day, according to distance from pump. The method of irrigation is by multiple furrows between rows of trees. The soil is a rather stiff, chocolate-colored loam.

There are four steam pumping plants and about six gasoline pumping plants now in that vicinity.

Irrigation is continued throughout the summer months from about May 1 to October 1. Trees over one year old receive water every five to six weeks; younger trees more frequently.

INDEX.

	Page.
Alta irrigation district, situation and organization of	24
Anderson Canal, description of	48–49
Arujo Ditch, description of	43
Ashe Ditch, description of	60
Bacigalupi Ditch, description of	89
Bacigalupi & Creighton Canal, description of	89–90
Bakersfield, examples of irrigation near	69–70
Ball & Harris Ditch, description of	82
Bond Ditch, description of	89
Beardsley Canal, description of	50–51
Browns Valley irrigation district, notes on	23–24
Buena Vista Canal, description of	49
Callison Slough, description of	81
Calloway Canal, description of	51–55
Carothers Ditch, description of	76
Castro Ditch, description of	48
Central irrigation district, location and area of	23
Cereals, furrow irrigation of	32
Checks (level), furrow irrigation in	33
College City irrigation district, location of	23
Colusa irrigation district, location and area of	23
Cost of preparing land for irrigation	67
Creasey Ditch, description of	75
Creech Ditch, description of	83
Deer Creek, irrigation from	76
Deer Creek Consolidated Ditch, description of	76
Dixon Canal, description of	61
Duty of water, examples of irrigation showing	69–75
Edwards Ditch, description of	58
Elrod Ditch, description of	88
Empire Ditch, description of	82
Emery Ditch, description of	55
Fancher Ditch, description of	83
Farmers Canal, description of	47
Farmers Ditch, description of	85
Fine Ditch, description of	80
Finney Ditch, description of	83
Fisher & Abley Ditch, description of	48
Flooding between parallel levees, description of	31–32
Flooding in contour checks, description of	27–29, 66
Flooding in level checks, description of	30–31
Flooding in rectangular checks (not level), description of	29–30
Frasier Ditch, description of	50
Fulweiler Ditch, description of	88
Furrow irrigation, description of	32–33
Gates Canal, description of	49
Gilliam Ditch, description of	87
Goose Lake Canal, description of	56
Great American Ditch, description of	84
Gully Ditch, description of	83
Henley Ditch, description of	50
Hively Ditch, description of	83
Hockett Ditch, description of	87
Hubbs & Miner Ditch, description of	87–88
Hunsaker Ditch, description of	88
Huron irrigation district, location of	25
Irrigation, methods of	26–36, 66–68, 92–94
State control and legal regulation of water supply for	19–22
Irrigation districts, details concerning	23–25
James Canal, description of	49–50
James & Dixon Canal, description of	58–59
Johnson Canal, description of	59–60
Joice Canal, description of	60–61
Jones Ditch, description of	83
Jones & Tuckey Ditch, description of	56
Kern and Tulare irrigation district, notes on	25, 63
Kern Island Canal, description of	43–45
Kern River, hydrography of	37–41
irrigation from	42–75
Kern Valley Water Company's canals, description of	61–63
Klein Ditch, description of	89
Kraft irrigation district, location of	23
Lamarsna Ditch, description of	89
Legal regulations of use of running water, methods of	19–22
Level checks, furrow irrigation in	33
Lindsay, pump irrigation at	94
Lone Oak Slough, description of	83
Madera irrigation district, location and area of	24
May Ditch, description of	60
McCaffery Ditch, description of	51
McCord Canal, description of	51
McGee, Putnam, & Caldwell Ditch, description of	87
Meacham Canal, description of	50
Mitchell, Springer, & Rose Ditch, description of	79
Modesto irrigation district, location and area of	24
M. M. Burnett Ditch, description of	88–89
Measurement of water, modes of	65–66
Newell, F. H., letter of transmittal by	11
Old English Ditch, description of	81
Old South Fork of Kern River, description of	46–47

UNITED STATES GEOLOGICAL SURVEY
CHARLES D. WALCOTT, DIRECTOR

IRRIGATION NEAR FRESNO, CALIFORNIA

BY

CARL EWALD GRUNSKY

WASHINGTON
GOVERNMENT PRINTING OFFICE
1898

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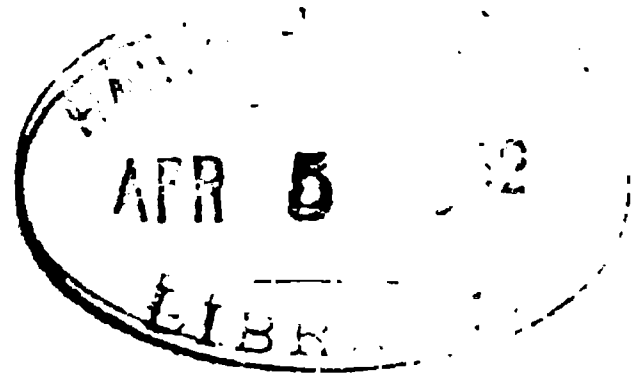


Chas Moore.

CONTENTS.

	Page.
Letter of transmittal	9
Kaweah River	11
Hydrography	11
Canals and ditches	14
Wutchumna Canal	14
Curtis & Lindsey Ditch	16
Venice Ditch (North Side Rocky Ford Ditch)	16
Elbow Ditch No. 1	16
Matthew Ditch, or Elbow Ditch No. 2	16
Curtis Ditch	17
Weston Ditch	17
Uphill Ditch	17
Settlers Ditch	17
Lakeside Ditch	18
Jennings Ditch	20
Rodgers Ditch	20
Modoc Canal	20
Hicks & Weston Ditch	20
Hayes Upper Ditch (Goshen Ditch)	20
Hayes Lower Ditch	21
Pogues Upper Ditch	21
Pogues Lower Ditch	21
Ogden Ditch	21
Hamilton Ditch	22
Consolidated Peoples Ditch	22
Swanson Ditch	25
Lee & Thompson Ditch	25
Rice Ditch	25
Catron and Teague ditches	25
Bliss & Hyde Ditch	25
Davis, Brown, and Pennebaker ditches	25
Extension Ditch	25
Kaweah Canal	26
Farmers Canal	27
Tulare Canal	28
Rocky Ford Ditch	29
Cameron Creek Company	29
Bacon & Crossmore Canal (Packwood Creek Canal)	29
Judd Ditch	30
Cutler & Higgins Ditch (Chatten Ditch)	31
Kaweah and Mill Creek Water Company	31
Oaks Ditch	31
Evans Ditch	32
Evans & Turner Ditch	32
Burch Ditch	32

Kaweah River—Continued. Page.
Canals and ditches—Continued.
Watson Ditch 32
Mill Ditch 32
Bahwell and Fulgham ditches 33
Longs Canal 33
Bostwick Cut 33
Ketchum Cut 34
Crowley & Mehrtens Ditch 34
Tulare irrigation district 34
Water supply, soils, and methods of irrigation 35
Kings River 39
Hydrography 39
Canals and ditches 42
Kings River & Fresno Canal 42
Fresno Canal 43
Centerville Ditch 47
Sweem Ditch 48
Fowler Switch Canal 48
Centerville & Kingsburg Canal 50
Selma irrigation district 52
Alta irrigation district (76 Canal) 52
Morrow Ditch 57
Dennis & Jordan Ditch 57
Kincaid Ditch 57
Glenn and Barton ditches 57
Emigrant Canal 57
Liberty Canal 58
Millrace Canal 58
Reeds Ditch 58
Laguna de Tache Canal (Grant Canal) 58
Crescent Canal 62
Peoples Ditch 62
Mussel Slough Ditch 64
Last Chance Ditch 65
Lower Kings River Canal 67
Rhoads Canal 69
Jacobs Canal 69
Sunset irrigation district 69
The Fresno plains 71
Description 71
The canal system 73
Loss of water by evaporation and seepage 74
Effect of irrigation on the water table 78
Methods of irrigating and duty of water 79
Wildflower 85
Liberty and Millrace settlements 86
Laguna de Tache Rancho 86
Mussel Slough country 87
Description 87
Canal system 87
Method of irrigation 88

ILLUSTRATIONS.

		Page.
PLATE	I.—Map showing canals from Kaweah and Tule rivers	11
	II.—*A*, Flume over Tulare Canal; *B*, Main canal of Tulare irrigation district	28
	III.—*A*, Canal regulator, Tulare irrigation district; *B*, Lateral, 1 mile south of Tulare	34
	IV.—Map of east side of San Joaquin Valley, from Kings River to Fresno River	38
	V.—Kings River at upper end of Centerville Bottoms, looking upstream	42
	VI.—*A*, Regulator on Kings River & Fresno Canal; *B*, Fowler Switch Canal near Sanger, looking upstream	44
	VII.—Cobblestone and brush dam of Fresno Canal, Kings River	46
	VIII.—Regulator of Fresno Canal on Kings River: *A*, As seen from above; *B*, As seen from below	48
	IX.—Regulator on Fowler Switch Canal: *A*, As seen from above; *B*, As seen from below	50
	X.—Regulator on 76 Canal: *A*, As seen from above; *B*, As seen from below	52
	XI.—*A*, Furrow irrigation for citrus fruits; *B*, Check weir in Alta irrigation district, in lateral, about 2 miles west of Traver	56
	XII.—Lower Kings River canal system	58
	XIII.—Peoples Ditch: *A*, Brush dam at time of high water; *B*, Regulator, as seen from above	62
	XIV.—Last Chance Canal regulator: *A*, As seen from upper side; *B*, As seen from below	66
FIG.	1.—Head of Wutchumna Canal	15
	2.—Head of Uphill Ditch	17
	3.—Head of Lakeside Ditch	19
	4.—Head of Consolidated Peoples Ditch	22
	5.—Ditch system at head of Kaweah Canal	26
	6.—Head of Farmers Canal	28
	7.—Head of Bacon & Crossmore Canal	30
	8.—Head of Bacon & Crossmore Cut	30
	9.—Discharge of Kings River at Red Mountain, California, 1896	41
	10.—Head of Kings River & Fresno Canal	42
	11.—Head of Fresno Canal	44
	12.—Head of Fowler Switch Canal	49
	13.—Head of Centerville & Kingsburg Canal	51
	14.—Wahtoke Reservoir, on 76 Canal	53
	15.—Head of 76 Canal	54
	16.—Plan and elevation of regulator for 76 Canal	55
	17.—Head of Grant Canal	60
	18.—Head of Peoples Canal, on Kings River	63
	19.—Head of Last Chance Ditch, on Kings River	66
	20.—Upper section of Lower Kings River Canal	68
	21.—Irrigation by filling subsoils with water, Mussel Slough country	89

LETTER OF TRANSMITTAL.

DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
DIVISION OF HYDROGRAPHY,
Washington, July 6, 1898.

SIR: I have the honor to transmit herewith a manuscript entitled Irrigation near Fresno, California, by Mr. C. E. Grunsky, and to recommend that it be published as one of the series of pamphlets on Water Supply and Irrigation. This is the second of three papers relating to irrigation in San Joaquin Valley, the other two being Nos. 17 and 19 of the series. It relates mainly to the irrigation systems deriving their water supply from Kaweah and Kings rivers, and covering the agricultural lands on the east side of San Joaquin Valley, between Visalia and Fresno.

Very respectfully,

F. H. NEWELL,
Hydrographer in Charge.

Hon. CHARLES D. WALCOTT,
Director United States Geological Survey.

IRRIGATION NEAR FRESNO, CALIFORNIA.[1]

By C. E. GRUNSKY.

KAWEAH RIVER.

HYDROGRAPHY.

Kaweah River enters San Joaquin Valley from the east, passing between Dillons Point on the north end and Wutchumna Hill on the south, about 15 miles east of Visalia. Its drainage basin above that point has an area of 619 square miles, mostly low mountain country. The river has a perennial flow, but its flow is comparatively small at low stages, ordinarily about 30 second-feet. The low-water period usually begins in August and continues through January. The river is subject to freshets in the winter months, and is at its highest stages in April, May, and June. Medium stages are expected throughout February, March, and July. The monthly mean flow at the river's highest stage exceeds 4,000 second-feet.[2]

Before the freshets of 1861–62, which have become memorable, the river annually overflowed large areas in its course across the east-side valley plain, and numerous high-water channels carried its waters toward Tulare Lake. The portion of its overflowed district to the east of or above Visalia is generally referred to as Visalia Swamp. Four of the river channels—Elbow Creek, Visalia or Mill Creek, Packwood Creek, and Deep Creek—gave the name of "Four Creek Country" to the vicinity of Visalia. The channel at the northern edge of the overflowed land was known as Canoe Creek above Iron Mountain, and as Elbow Creek below that point. The course of Elbow Creek is north of west to a junction with Cottonwood Creek, a small water course from the northeast, thence southwesterly to a reunion with Kaweah River water in Cross Creek, which name is given to the lower portion

[1] For an account of irrigation in other parts of San Joaquin Valley, see Water-Supply and Irrigation Papers Nos. 17 and 19. These three papers are based largely upon information collected by the State engineering department of California ten years ago, and are intended to supplement the two volumes issued by that department, namely: Irrigation Development, History, Customs, Laws, etc., in France, Italy, and Spain, by Wm. Ham. Hall, C. E., State Engineer, Sacramento, California, 1886; and Irrigation in California (Southern), Part 2 of Report of Wm. Ham. Hall, C. E., State Engineer of California. 1888. (See introductory paragraph on page 13 of Water-Supply and Irrigation Paper No. 17.)

[2] Physical Data and Statistics, Wm. Ham. Hall, State Engineer of California, pp. 455, 476.

of St. Johns Channel of the river. Deep Creek was the principal south marginal stream. It received water from the main channel of the river 8 miles east of Visalia and lost its identity about 5 miles southeast of Visalia, where its waters spread and were received into other channels of different names. Visalia Creek and Packwood Creek were the names given to the two water courses into which the main channel of Kaweah River separated 5 miles above Visalia. The course of Visalia Creek was westerly through Visalia, that of Packwood Creek southwesterly. To understand the changes made in the system of principal channels of the river by the high waters of 1862 and the effects of these changes, it is necessary to know that, even preceding that year, irrigation and drainage work had been done in the Kaweah River delta. The Shipp Cut had been made in 1854. It was a small drain ditch from the swamp, near where Rocky Ford now is, southwesterly to a connection with Canoe Creek. A canal had been constructed from Visalia Creek into Visalia to supply power to a flour mill. The Lander Ditch, the Watson Ditch, and a number of other small ditches from Visalia and Packwood creeks had also become dependent upon the flow of water in the river channels at the south of Visalia. The freshets of 1861–62 cut a new channel from a point on Kaweah River about 14 miles east of Visalia in a northwesterly direction toward and along the northern border of Kaweah River Swamp. Shipp Cut and a section of Canoe Creek were enlarged by the flood waters and became a part of this new channel, and finally a connection was established with the Cross Creek channel below Visalia, and thus St. Johns Channel of Kaweah River was permanently established. At the same time a new high-water channel was washed out toward the northeast from a point on Kaweah River 6 miles above Visalia to a connection with this new channel. This is known as Sand Slough, which still remains as a connection between the two river channels at a point where they are only about one-half mile apart. The same high waters caused so much erosion in Landers Ditch that it became a branch of the river, and is generally referred to as Landers Slough. Its upper portion was long in use as the channel through which the Consolidated Peoples Ditch received its water.

The upper sections of the original main channel of Kaweah River were obstructed by the drift and silt deposits of these freshets, and as the low-water period of 1862 approached, it was found that water was scarce for those depending upon Deep Creek, Packwood Creek, and Visalia Creek for their supply, and many projects were proposed for relief. During the years immediately following, a number of ditches were constructed from the St. Johns Channel of the river, near Rocky Ford, southwesterly to the original main channel. Such were Longs Canal, Ketchum Canal, and the Bostwick Cut. All of these were intended to increase the flow in the delta streams at and southward of Visalia. After much contention between settlers on these several streams as to

the apportionment of their scant supply of water, it was agreed, in 1867, that a gate should be constructed in the head of Visalia Creek. This gate was not, however, maintained long. The freshets of 1867–68 were almost equal to those of 1861–62 and effected further enlargement of the St. Johns Channel. They refilled and otherwise destroyed some of the ditches that had been opened as connections between the two rivers. They washed out the gate in the head of Visalia Creek, and partially closed the heads of Packwood and Deep creeks. They enlarged Sand Slough. At the same time the upper portions of the old channel of Kaweah River were further obstructed by drift and silt, and a new head of St. Johns Channel was eroded about a mile above the former point of separation of the two channels.

To overcome the increased difficulties of keeping a good supply of water in those channels of the river reaching the vicinity of Visalia, many ineffectual efforts were made and much money was almost uselessly expended until, in 1877, a contract was entered into with Mr. Samuel Fowler by the Kaweah Canal and Irrigation Company, the Consolidated Peoples Ditch Company being an interested party, to open the old channel of the river. The cut then made, practically following the old channel, was enlarged and deepened by erosion, until a few years thereafter it was again the low-water channel of Kaweah River. Another obstructed section of the old channel near the head of the Consolidated Peoples Ditch, about 10 miles east of Visalia, was improved about the same time by the Kaweah and Mill Creek Water Company, and has since been known as the Visalia Cut or Hamilton Cut.

The obstructed head of Packwood Creek was improved by the Rocky Ford Canal Company, but was not in service long. This creek now receives its principal supply of water through the Bacon & Crossmore Cut from Visalia Creek. It has a southwesterly course, and such of its water as is not used for irrigation is delivered into Tulare Lake.

Cross Creek has already been mentioned as receiving the water of St. Johns Channel, Elbow Creek, and Cottonwood Creek. After approaching within 4 miles of Traver its course becomes southwesterly to a union with some of the old high-water delta channels of Kings River. Its course is thence southerly along the eastern border of this delta to Tulare Lake, which receives its water.

Visalia or Mill Creek separates into two channels soon after passing through Visalia. The course of one of these is a little north of west, that of the other southwest. Both unite with Cross Creek before reaching Tulare Lake.

Cameron Creek is one of the lesser delta channels of Kaweah River. It receives a portion of the flow of Deep Creek at a point about 6 miles due east from Visalia, and has a southwesterly course to Tulare Lake. It passes just to the northward of Tulare. An artificial channel at the head of this water way, constructed to improve its connection with Deep Creek, was closed by an order of court some years ago.

Deep Creek has already been mentioned. Its waters at the spread or sink of the creek were conducted by small artificial channels into Lower Deep Creek and Bates Slough. These artificial channels were soon so enlarged by erosion that the two lower sloughs have become extensions of the Deep Creek channel and conduct its waters onward southwesterly toward Tulare Lake.

Outside Creek has a course along the eastern margin of the Kaweah delta. The creek can not be traced to a direct connection with the present river channels. It may, in fact, be regarded as the extension into the river delta of Yokohl Creek, a small stream draining a portion of the foothill section intermediate between the Kaweah River and Tule River drainage basins; but in times of flood the natural flow of some of the river water was into depressions, reaching a point that may be regarded as the head of Outside Creek, about 9 miles east of Visalia. The creek now receives an occasional inflow of foothill drainage waters from the east and the waste water from some of the branches of the Consolidated Peoples Ditch. The water of Outside Creek is distributed to a number of channels, the most southerly of which is Elk Bayou, which unites southeast of Tulare with the old channel of Tule River, and thence has a southwesterly course to a union with the present main channel of Tule River.

CANALS AND DITCHES.

Wutchumna Canal.—This is the upper north-side diversion of water from Kaweah River. The head of the canal is at the base of the slope of Dillons Point, a foothill spur rising to the northward. Thence it has a westerly course for 4 miles to a flat depression, which its water converts into a lake of about 40 acres, known as Bravo Lake. Leaving Lake Bravo, the westerly course of the canal is maintained 4 miles farther to the northern base of Iron Mountain, and thence 6 miles southwesterly to St. Johns Channel, about 4 miles above Visalia, where its water is carried over the river channel in a flume. The main canal then flows westerly near the south bank of the river about 2 miles to a junction with Old or Lower Wutchumna Ditch, whose branches extend far to the west of Visalia.

The Wutchumna Water Company was incorporated in 1872 for the avowed purpose of effecting a better distribution of water to the several ditches dependent upon Kaweah River for their supply, but various difficulties were encountered which prevented the enterprise from meeting with anticipated success, and it was not until 1880 that a connection between the upper diversion—work on which is reported to have commenced in 1872—and the distributing system of the lower canal was finally established. The lower canal was constructed in 1873 or 1874. Its head is on the south side of the St. Johns Channel of Kaweah River, about 3 miles northeast from Visalia. It established a direct southerly connection between St. Johns River and Visalia Creek,

and for three years its water furnished power for the flour mill in Visalia. The principal branch of the Lower Wutchumna Canal has a westerly course, passing just to the north of Visalia and terminating at a point about 4 miles south from Goshen.

The first work at the head of the Wutchumna Canal seems to have been done by Stephen Barton, who subsequently appears as one of the directors in the Pioneer Canal Company, which was incorporated in 1877, and which during that season constructed a ditch on the line adopted by the Wutchumna Canal as far as Bravo Lake. When the Wutchumna Canal Company, as successor of the Pioneer Company, assumed control, this upper ditch was extended along the route already described.

The canal head gate or regulator has been placed in a rock cut, and, as a result of this location of the head of the canal, expenditures of maintenance became unusually heavy when, a few years after the canal came into use, it became necessary to cut the upper section of the canal 4 feet deeper. This was done at a cost of $6,000. The total cost of canal construction has probably exceeded $60,000. The head gate width is 20 feet, and this may be regarded as the average bed width of the canal throughout its principal section. Its fall is reported to be nearly 7 feet to the mile for 4 miles, thence 2½ feet to the mile. The flume across St. Johns River is 14 feet wide, 2 feet deep, and about 150 feet long. It was built in 1880. The head gate of the Lower Wutchumna Canal is a little over 11 feet wide.

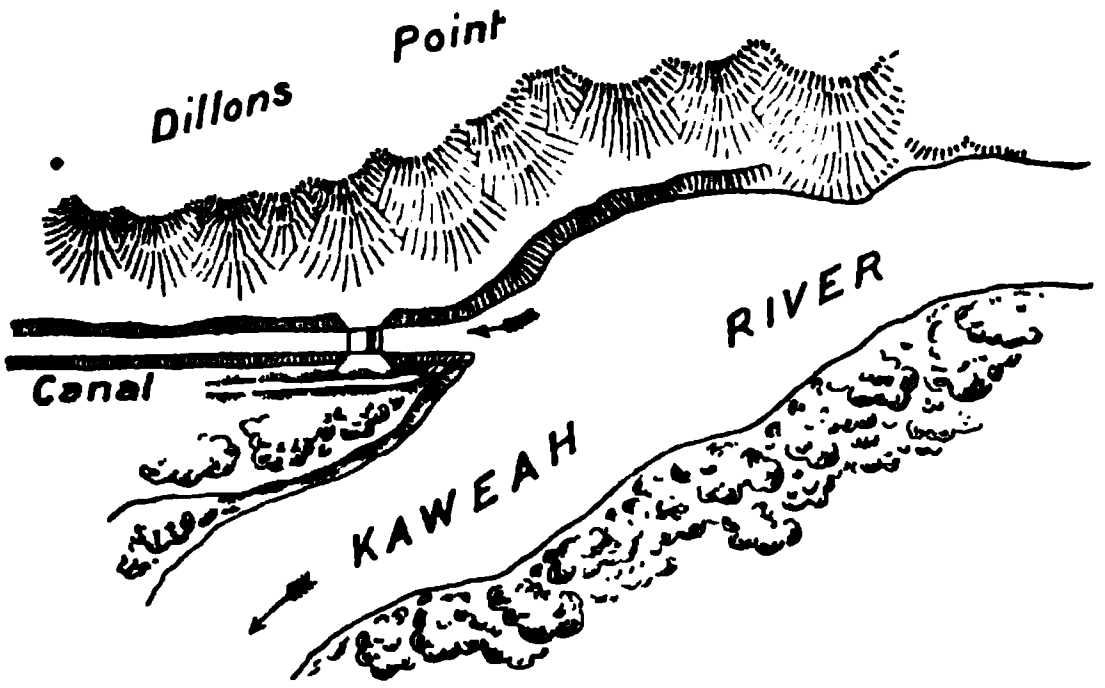


FIG. 1.—Head of Wutchumna Canal.

For a distance of about 4 miles westward from Lake Bravo the canal follows the original alignment of the Curtis & Lindsey Ditch. This ditch was enlarged, and its owners were granted a right to use that section of the Wutchumna Canal.

The canal is owned by an incorporated company whose shares are all in the hands of about thirty persons. All canal expenses are met by assessment of the stockholders. Each stockholder is entitled to a proportional part of the water in the canal, and he may dispose of this at his pleasure. He may lease this to whom he pleases, but not in less amounts than full shares. The distribution of water is in charge of a canal superintendent, who apportions it to the various distributing ditches in proportion to the number of shares represented in each. Although the company owns some of the shares of stock, these are not

for sale, nor will the company lease them or the water which they represent. By retaining these the company increases the proportional part of water represented by each of the other shares. The canal company bears the expense of the necessary structures at the heads of distributing ditches, but does not keep them in repair or replace them if destroyed. This has to be done under direction of the canal superintendent by the parties directly interested in their maintenance.

Curtis & Lindsey Ditch.—This ditch has its head on the north side of St. Johns River, 4 miles below the head of the Wutchumna Canal. It has a northwesterly course for one-half mile to a connection with the Wutchumna Canal, into which it drops its water. Four miles below this point the water dropped into the Wutchumna Canal is again taken out by a ditch 4 miles long having a northwesterly course and terminating on the bottom lands of Cottonwood Creek. The Curtis & Lindsey Ditch was constructed in 1876, and its extension toward Cottonwood Creek was made in the following year. Soon afterwards 4 miles of its course were adopted as the alignment for the Wutchumna Canal, so that the ditch now appears in two sections, of which the lower one may also be considered a branch of the Wutchumna Canal. The ditch is also known as the Curtis, Lindsey & Moffitt Ditch. Its width was about 10 feet on the bottom, and its fall between 2 and 3 feet to the mile, but, so far as known, the extent of irrigation from it has not exceeded several hundred acres.

Venice Ditch.—This, called also North Side Rocky Ford Ditch, is a small north-side ditch which seems to have been first used about 1873. It was extended and enlarged somewhat in 1877. Its head is at Rocky Ford. It has a westerly course to Iron Mountain, thence skirts the eastern and southern base of this mountain, and terminates 2 miles farther west. It is about 6 miles long and 3 to 8 feet wide. Ownership in the ditch is represented by shares held by the farmers who use its water.

Elbow Ditch No. 1.—The flow of Elbow Creek, which leaves St. Johns River at a point about 5 miles above Visalia, is controlled, in a measure at least, by a regulator or head gate 8 feet wide, and is frequently referred to as Elbow Ditch No. 1. The upper part of the creek is an enlargement by erosion of a portion of the ditch known as Shipps Cut, which was constructed in 1854.

Matthew Ditch, or Elbow Ditch No. 2.—This is a small ditch having its head on the north side of St. Johns River, about 2 miles below the head of Elbow Creek. It was constructed in 1855, but with a somewhat different alignment from the present. The freshets of 1861–62 so changed the position and character of Kaweah River that the head of the ditch had to be carried upstream. It is difficult to determine whether the ditch remained in continuous use. The head gate was put into the new ditch in 1875 and was set somewhat lower than the bed of the river. A few years later erosion had progressed in

the river channel to such extent that a wing dam had to be used to divert water into the ditch. The ditch has a northwesterly course, is about 6 miles long, 6 feet wide on the bottom, carries water about 1½ feet deep, and has a grade of about 6 feet to the mile. It irrigates between 200 and 300 acres, of which nearly one-half is alfalfa.

Curtis Ditch.—About 1879 there was a small ditch in use occasionally for the irrigation of a few acres of alfalfa on the north side of St. Johns River about a mile below the head of the Matthew Ditch. It was known as the Curtis Ditch, and has fallen into disuse.

Weston Ditch.—Another abandoned small ditch which was in use for a few seasons prior to 1880 on the north side of the river, about a mile above the head of the Uphill Ditch, was the Weston Ditch.

Uphill Ditch.—This is another north-side ditch. Its head is half a mile above the road leading northward from Visalia. Diversion is made from the river without the use of any permanent weir. The diverted water is led in a cut a few hundred yards northwesterly and is dropped into a natural depression or high-water channel, in which it continues on the same course half a mile. Thence it is taken in the ditch proper northerly about 3 miles to the place of use in the vicinity of Elbow Creek. The head gate is 8 feet wide. It is in the form of a box culvert, and bears a heavy fill of sand on top, intended to give it stability. The sand deposits in the cut to the river above the head gate have made it somewhat expensive to keep the head of the ditch open. The ditch was constructed in 1871. It was made 8 feet wide on the bottom, and was intended to carry water 2 feet deep. Its fall is 20 inches to the mile.

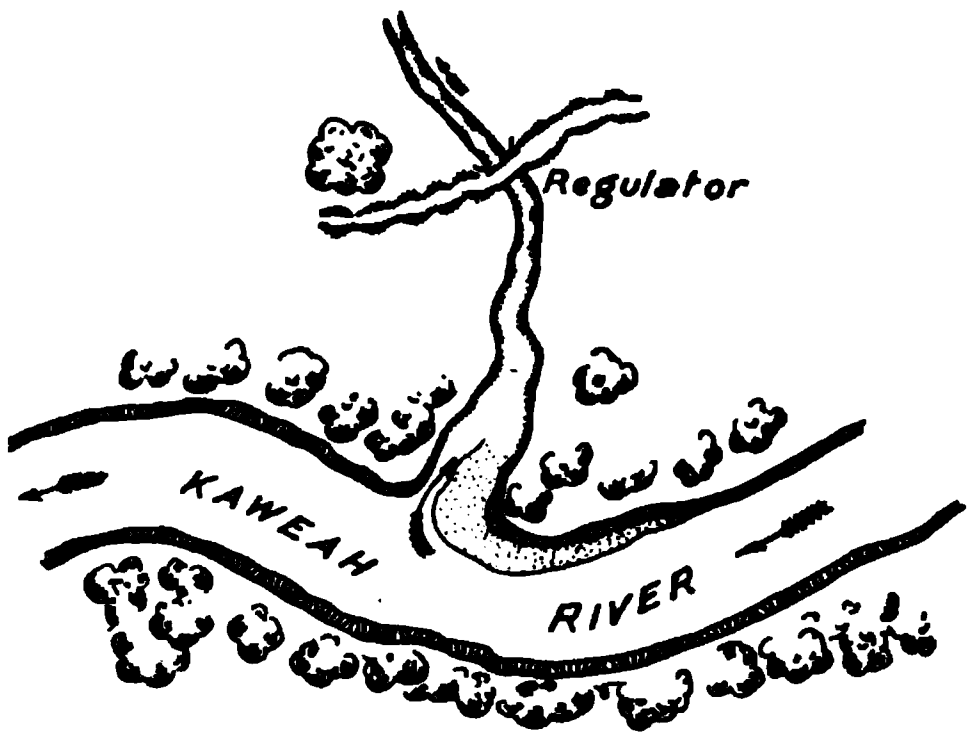


FIG. 2.—Head of Uphill Ditch.

Settlers Ditch.—This is a canal which for many years was of considerable importance as a source of water supply for lands in the eastern part of the Kings River delta. The canal receives water through a branch of Cross Creek. The canal regulator is on the north side of that creek 3 miles south of Traver. The creek channel, there tapped by the canal, is really the extension of Cottonwood and Elbow creeks, but most of its flow comes through a cut, the real head of Settlers Ditch, a quarter of a mile long, leading from the main channel of Cross Creek to its northern branch, at a point about 4 miles above the Settlers Canal head gate. Where the canal is finally diverted from Cross Creek a light timber weir or waste gate has been placed across the

creek channel. The canal regulator is nearly half a mile below the point where the canal leaves the natural channel. The head gate is 32 feet wide. It has eight openings, each 3 feet 6 inches wide in the clear. The gates closing these openings are provided with stems to which power is applied by means of levers.

The canal proper has a bed width at and near its head of 32 feet, and can carry water 2½ feet deep. It has 9 inches fall to the mile, and a capacity of 75 to 80 second-feet. The width of the canal is reduced within 3 miles of its head gate to 24 feet on the bottom, and its fall to 6 inches to the mile. Its course is a little south of west for 5 miles to a point where its water is divided, being carried thence southerly in two channels, of which the easterly branch is about 4½ miles long, and the westerly about 7 miles. The ditch commands a territory of about 8,000 acres, of which as much as 5,000 acres have been benefited by its water in a single season. The canal construction commenced in 1874, and considerable land was irrigated in 1876. Water was available only during the high stages of Kaweah River.

There was but little irrigation with water from this canal at any time to the east of the Kings River delta lands, soils being too alkaline to encourage cultivation. The extent to which this canal is now in use is somewhat problematical, as all the rights to water which it was supposed to have acquired were sold to the Tulare irrigation district, which has made a diversion from the St. Johns River about one-half mile below Rocky Ford. The canal is still in service, and does not appear to have suffered great diminution in its supply of water during the high-water stage of the river. The Settlers Ditch Company, which built the Settlers Canal at a first cost of approximately $35,000, was incorporated in 1874 with a capital stock of $10,000, in 50 shares of $200 each. These were held, at the time of the sale of the canal water rights, by about 50 persons.

All expenses of construction, repairs, maintenance, and management have been met by assessing the stockholders. Each share of stock entitles its holder to a proportional part of the water in the canal. Water is apportioned to each branch and to each distributing canal in proportion to the number of shares for which each draws water. No water is sold by the canal company, nor does the company lease any of the several shares which have reverted to it. Each stockholder, however, is permitted to lease his water to other persons, and can have it delivered to any point of the main canal or its branches which he selects. Water is delivered to irrigators through gates of various forms, generally under pressure. Its equitable distribution depends to a great extent on the judgment of the superintendent. Each share of water is supposed to be sufficient to irrigate 160 acres. The cost of water to the irrigators has averaged about 70 cents per acre per annum.

Lakeside Ditch.—This is another important diversion from the lower

portion of Cross Creek. The head of this canal is 4 miles below the head gate of the Settlers Canal, and 6 miles west from Goshen. The diversion from the natural creek channel is accomplished, as in the case of the Settlers Canal, by means of a weir or waste gate placed in the creek channel below the head of the canal, and a regulator or head gate in the latter about one-half mile below its head. The weir is a light timber structure arranged as a series of gates. It has a total width of 41 feet. Its nine openings between vertical posts are each 4 feet wide in the clear. The canal head gate has a width of 31 feet. The space between side walls is divided by vertical posts into six openings, each about 4½ feet wide in the clear. These openings or spaces between posts are closed with vertically sliding gates, to the stems of which power is applied by means of levers. The canal has a southwesterly course from its head for about 3 miles. In this distance it has a bed width of 30 feet and a fall of 6 inches to the mile. It can carry water about 3 feet deep. Its branches extend in southerly and southwesterly directions to the vicinity of Tulare Lake. The main canal and principal branches have an aggregate length of about 50 miles and command about 20,000 acres of land. The cultures on at least as much as one-half of this area may be considered to have been benefited by irrigation from this canal in a single season. The canal was constructed in 1874 and the years immediately following, at a total first cost of about $35,000.

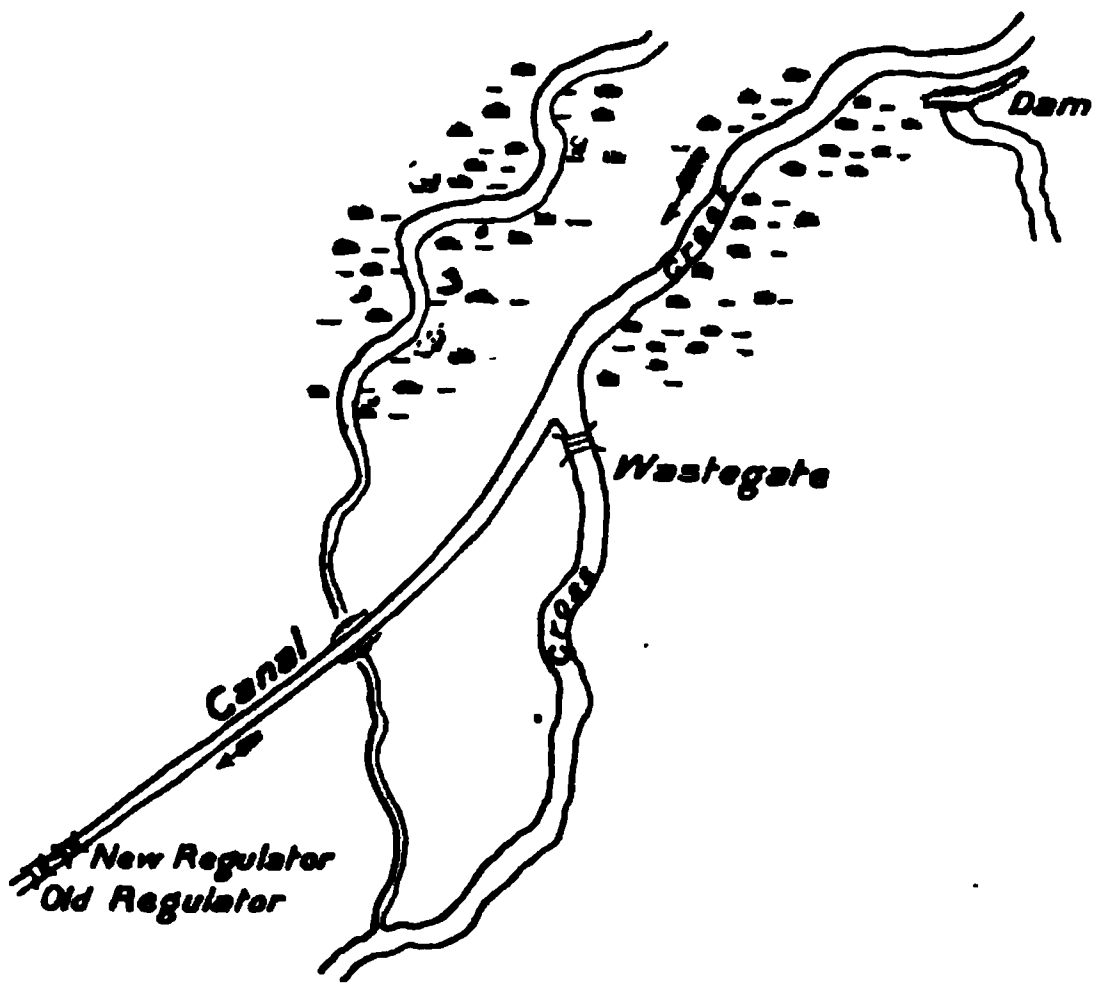


FIG. 3.—Head of Lakeside Ditch.

The canal is owned by the Lakeside Ditch Company, which was incorporated on August 7, 1874, with a capital stock of $10,000, divided into 10,000 shares of $1 each. On February 20, 1875, the capital stock was increased to 30,000 shares of $1 each. These shares were owned by ninety-five persons in 1885. Each share of stock entitles its holder to a proportional share of water in the canal. The canal company does not sell or rent water, not even on the few shares of stock held in the company's name. Each stockholder can have his water delivered at any point of any branch of the company's canal system. He can, if he desires, rent or sell his water for one or more

seasons. The company originally intended to deliver to each stockholder the water to which he was entitled at some point on his own land, but this system of delivery was found to be inexpedient and was abandoned in 1876. The distribution of water is in charge of a canal superintendent, who apportions the water to the various branches of the canal and has control of its delivery to the irrigator. The average annual cost of water from this canal has been about $1.55 per acre.

Jennings Ditch.—This is a small ditch which has its head on the south side of St. Johns River a little more than a quarter of a mile below the head of the Lower Wutchumna Ditch, and sends its branches into the northern portion of Visalia and adjacent territory. The main ditch has a bed width of 10 feet. The diversion of water is accomplished by means of a light wing dam of sand and brush, and the flow of water in the ditch is controlled by means of a simple regulator in the form of a box, 10 feet wide, which can be closed with loose flashboards. Water rights of an old date, preceding the formation of St. Johns River, are claimed for this ditch, whose head has been shifted back and forth between Mill Creek and St. Johns River.

Rodgers Ditch.—This is a small ditch, about 4 feet wide on the bottom, which supplies water to a few acres of land north and west of Visalia. It was constructed about 1875.

Modoc Canal.—This canal or ditch was originally intended to be made a distributary for the Wutchumna Canal water. It was constructed in 1876. Its head is on the south side of St. Johns River, just above the road leading northward from Visalia. Its length is about 4 miles, the course being a little south of west. Its bottom width is about 10 feet, and its capacity about 36 second-feet. Ownership in the ditch is represented by shares of stock. Water is distributed to stockholders in proportion to their interests. The annual expense of maintenance is about $100, which covers the construction of an inexpensive wing dam at the head of the ditch. The area actually irrigated is about 1,000 acres.

Hicks & Weston Ditch.—This is a very small ditch from the south side of St. Johns River, about 200 yards above the Modoc Canal. The ditch is 4 to 5 feet wide on the bottom. It was constructed in 1879. It receives water from the Wutchumna Canal in addition to its independent supply, and is sometimes called the Hicks Branch of Wutchumna Canal.

Hayes Upper Ditch (*Goshen Ditch*).—This ditch was constructed in 1881 or 1882 to supplement an older small ditch which was constructed in 1874 for the irrigation of lands near Goshen, theretofore considered almost worthless on account of the abundance of alkaline salts in the soil. The upper ditch has its head on the south side of St. Johns River about 4 miles northwest of Visalia. It has a westerly course and is about 4 miles long. Its dimensions are irregular. The pro-

moters of this enterprise constructed a small ditch and gave it an inexpensive, poorly protected head gate. The gate was carried off by the first freshet and the ditch was rapidly enlarged by erosion, so that it became a canal of considerable capacity. The second regulator put into its head was also a very light structure, 18 feet wide. Like many of the structures on Kaweah River, it was arranged as a box culvert, the entrance to which was divided into nine openings by vertical posts. The spaces between posts could be closed with loose flashboards. This ditch and the Lower Hayes Ditch both belong to the same owner, who has supplied some water to his neighbors at agreed rates per acre.

Hayes Lower Ditch.—The head of this ditch is about 1½ miles below the head of the Hayes Upper Ditch. Its course is a little south of west to the same region watered by the Hayes Upper Ditch. The ditch is about 4 miles long and 6 feet wide. Its head gate has a width of 10 feet. This ditch was constructed in 1874 by settlers near Goshen, but soon fell into the hands of the promoters of the Goshen Canal enterprise.

Pogues Upper Ditch.—This is the uppermost south-side diversion from Kaweah River. The head of the ditch is about 4 miles above the head of St. Johns River, a mile above the hill known as Limekiln Point. The ditch, which has a bed width of about 6 feet, skirts the northern and western base of Limekiln Point and commands several thousand acres of fine land lying between projecting spurs of the foothills. The ditch was constructed in 1884. Water is carried in a flume for some distance from the head of the ditch. This ditch now serves the citrus orchards at Lemon Cove, which have been set out within the last four or five years and now have an aggregate area of about 500 acres.

Pogues Lower Ditch.—This ditch was constructed in 1875. It diverts water from the south side of Kaweah River just below Limekiln Point. It has a southwesterly course, a bed width of 6 to 8 feet, and passes to the north and west of Wutchumna Hill, following the eastern border of the main valley and terminating at present at a point about 3 miles southeast of Exeter. Its total length is about 15 miles, and the capacity claimed for it is 30 second-feet. There was but little irrigation from this ditch at the time the second Pogue Ditch was constructed, but demand for water is rapidly increasing. The water is used on the lands set out to citrus fruits at and near Bonnie Brae. The area of citrus fruits now set out, all being dependent on this ditch for water, is 550 acres. Purchasers of land from the owners of this ditch are granted the right to call for water at the rate of 1 miner's inch (about one-fiftieth of a second-foot) to 5 acres. The charge of the water is 8 cents per inch per twenty-four hours. The lands (including the water rights) are sold at $75 per acre.

Ogden Ditch.—This ditch has its head on the south side of Kaweah River, about three-quarters of a mile below the head of Pogues Lower

Ditch. It has a southwesterly course, closely following the river, and terminates near Cottage. It is a very small ditch, about 4½ miles long, and supplies water to a few acres of alfalfa. It is said to be one of the old ditches, the date of its construction being given as 1862. The head of the ditch was not, however, always maintained at the same place, this having been impossible on account of the changes in the alignment and character of the river.

Hamilton Ditch.—This is another small private ditch on the south side of Kaweah River. Its head is about a mile above Cottage. It has a southwesterly course, is about 4 miles long, and about 4 feet wide. It has been in use since 1854. A south-side branch of the Hamilton Ditch is sometimes known as the Dillon Ditch.

Consolidated Peoples Ditch.—The difficulties experienced by irrigators

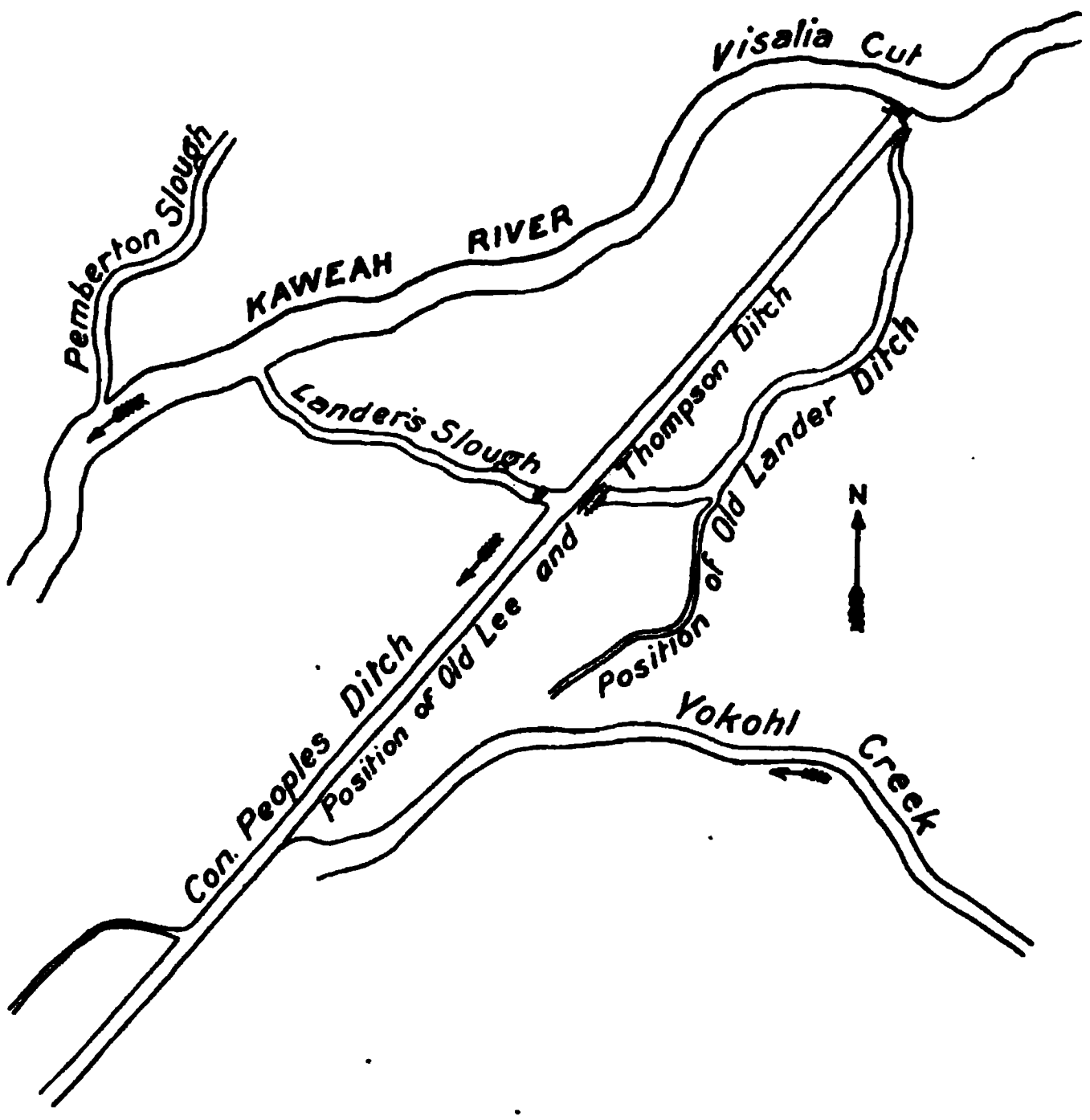


FIG. 4.—Head of Consolidated Peoples Ditch.

dependent for water upon the flow of Deep Creek, Packwood Creek, and Visalia Creek, after the freshets of 1861–62, led to a combination of interests, the direct result of which was the construction of the Peoples Ditch. The outlook for a sufficient supply of water was particularly bad after the winter of 1863–64, in which there was an unusual deficiency of precipitation, and, as a result of a conference with the owners of a number of small irrigation ditches, about one hundred interested persons assembled late in February, 1864, at the point where Landers Slough leaves the river and commenced work on the Peoples

Ditch, the water of which was to be apportioned to a number of ditches which before made independent diversions. The principal ditches that then became dependent upon the Peoples Ditch for water were the Landers, Lee & Thompson, Swanson, Turner, Grubbs, and Rice ditches. The expense of the canal construction was apportioned to the participating farmers according to relative interests. Most of them contributed labor, teams, and supplies. The ditch at its head was made 18 feet wide and 4 feet deep and was to have a fall of about 3½ feet to the mile. Work progressed rapidly and the ditch was considered finished by June 1, 1864. Its estimated cost at that time was $11,000. But owing to the obstructed condition of the old channel of Kaweah River below the head of St. Johns Channel, expectations as to flow of water were not fully realized, and upon petition the water commissioners of Tulare County granted the ditch company a franchise to remove obstructions from the old Kaweah River channel and to enlarge it where necessary to a width of 20 feet. Under the franchise work was done on the old river channel to a point near the present head of St. Johns River, about 4½ miles above the present head of the ditch. The river channel was thus kept open until again filled, in places, with drift and silt by the freshets of 1867–68. These freshets washed out the canal head gate in Landers Slough and considerably deepened and enlarged the upper section of the canal. During the period intervening between that winter and 1877, when the making of the Fowler Cut resulted in the practical reestablishment of the old channel of Kaweah River, water reached the head of the Peoples Ditch through a number of high-water channels leading in a southwesterly direction from the upper section of St. Johns River through Visalia Swamp. When water became scarce at the head of the canal, men would be sent up to St. Johns River to increase the flow toward the south by throwing obstructions into that river channel or by opening a better passage through the swamp. There has been a satisfactory supply of water to the head of the Peoples Ditch ever since the Fowler Cut was made.

This cut was made by Mr. Samuel Fowler under contract with the Kaweah Canal and Irrigation Company, which had entered into an agreement with the management of the Peoples Ditch concerning the apportionment of water. The agreement, which was formally executed on December 21, 1878, but subsequently set aside by a decision of the courts, provided for a joint ownership of the upper portion of the Peoples Ditch and of the water way above the head of that ditch as improved by the Kaweah Canal and Irrigation Company, and conceded to the Peoples Ditch the right at all times to as much water as will flow in a ditch 50 feet wide and 2 feet deep on a grade of 6 inches to the mile. The water of Kaweah River which passes the head of St. Johns Channel separates into two channels, each about a mile long, forming an island about 11 miles above Visalia. The upper portion of the

northernmost of these channels is known as the Hamilton or Visalia Cut. The southernmost is Lander Slough, or the enlarged channel of the Lander Ditch. It is the upper portion of Lander Slough which until 1896 carried water to the point where the flow was brought under final control for the Peoples Ditch. But when the canal regulator failed Landers Slough was closed near its head and an artificial canal was substituted for the Landers Slough section of the Peoples Ditch. A box inlet 20 feet wide and 10 feet deep is maintained in the head of this new canal section, which structure seems to be intended more as a partitioner of the flow of Kaweah River than as a regulating gate in the ordinary sense.

The Consolidated Peoples Ditch has a southwesterly course from Landers Slough for 3 miles to the point where its water was separated from that of the Kaweah Canal, so long as that canal was in service. The main canal extends from that point about 1½ miles farther, to a point known as Dillons Mill, where some of its water is in use to supply power. The section of the canal next below Landers Slough follows the original alignment of the Swanson Ditch for about three-fourths of a mile, following and finally crossing the almost obliterated channel of Yokohl Creek. The occasional flow of this creek is admitted into the canal, and surplus waters are discharged through a waste gate into Outside Creek, which was originally a continuation of the Yokohl Creek channel. The main canal is of somewhat irregular dimensions, much of it having the appearance of a natural channel. Its width is generally 30 to 50 feet and its capacity probably exceeds 400 second-feet.

The consolidation of the interests of the several small ditches and individual irrigators, as already explained, led finally to an incorporation of their organization. This was effected in 1874, and the corporation received the name of the Consolidated Peoples Ditch Company. Its capital stock was fixed at $9,700, in 97 shares of $100 each. Canal expenses are assessed upon stockholders. No water is sold by the canal company. At the time of constructing the canal it was agreed that each person interested in the main canal should contribute toward construction down to the point at which his water was to be delivered into a branch ditch. All branch ditches are under independent management. Water is distributed to the various branch ditches, under the direction of the president of the company, in proportion to the number of shares of stock for which water is to be delivered to each. The apportionment of water between the main canal and a branch ditch is accomplished by constructing a sill or floor at the same elevation in each, the effective width of canal and ditch on each sill being made proportional to the amount of water to be passed. The cost of constructing and maintaining these structures falls upon the canal company. The area of land actually irrigated in a single season with water from the Peoples Ditch has exceeded 5,000 acres. The total expendi-

ture on the main canal chargeable to the construction account has been about $50,000.

Swanson Ditch.—This is a branch of the Peoples Ditch, receiving its water about three-quarters of a mile below the point where the latter leaves Landers Slough. It has a southwesterly course and is about 4 miles long. It is reported to have been in use as an independent ditch as early as 1855. While the supply of water from the Peoples Ditch was somewhat unreliable—preceding 1878—irrigators dependent upon the Swanson Ditch endeavored to keep the head of Packwood Creek open, but with indifferent success. Since that time the ditch is to be regarded merely as a branch of the Peoples Ditch.

Lee & Thompson Ditch.—This was a second old ditch, almost parallel with the Swanson for some distance. Its alignment was adopted for the Peoples Ditch for a considerable distance, and only the lower end of the original ditch remains in use as a small distributary of the Peoples Ditch water.

Rice Ditch.—This is another small ditch, now a branch of the Peoples Ditch, which was in use before the latter was constructed. Its course is southerly from a point near the lower end of the main ditch. It is about 6 miles long, terminating in a branch of Outside Creek used as a distributary of the Peoples Ditch water under the name of the Bliss & Hyde Ditch, and it commands a narrow strip of land lying to the east of Outside Creek.

Catron and Teague ditches.—These are two small branches of the Peoples Ditch, both of which receive water from the south side of the latter through a common head about 2 miles below Landers Slough. Their course is southerly. The former is about 3 miles long, the latter about 4, and both are connected at their lower ends with the Rice Ditch, into which surplus water is dropped.

Bliss & Hyde Ditch.—This is a branch of the Peoples Ditch, receiving its water a quarter of a mile below the head of the Catron and the Teague ditches. At that point a short cut from the south side of the Peoples Ditch drops water for this branch into a natural channel—the eastern branch of Outside Creek—which is the same channel used above that point as a common head for the Catron and the Teague ditches. This channel has a course a little west of south for about 12 miles, to the point where the water of the branch ditch is used, about 6 miles east of Tulare, on both sides of Outside Creek, there known in part as Elk Bayou. Water is diverted from Outside Creek into two irrigation ditches, one upon either side, each of which has a length of about 2 miles.

Davis, Brown, and Pennebaker ditches.—These are three short branches of the Peoples Ditch, all receiving water from it at or near the termination of the main canal, and supplying water to lands near Farmersville.

Extension Ditch.—After the use of a portion of the water of the

Peoples Ditch for power at Dillons Mill, which is at the termination of the main canal, it flows into Outside Creek. The creek channel is closed with an overfall dam of brush, which serves as a waste way for all water not required for the Extension Ditch. This ditch is one of the principal branches of the Peoples Ditch. It has a southwesterly course, and, with its branches, commands the region to the west and northward of Farmersville. It was built by the farmers whose lands it waters. They have formed a corporation known as the Extension Ditch Company, whose shares of stock are in the hands of thirty or more irrigators. The affairs of this company are managed entirely independent of the Peoples Ditch Company, which merely delivers to it the water which its stockholders are entitled to receive from the Peoples Ditch.

Kaweah Canal.—The enumeration of this canal is merely historical.

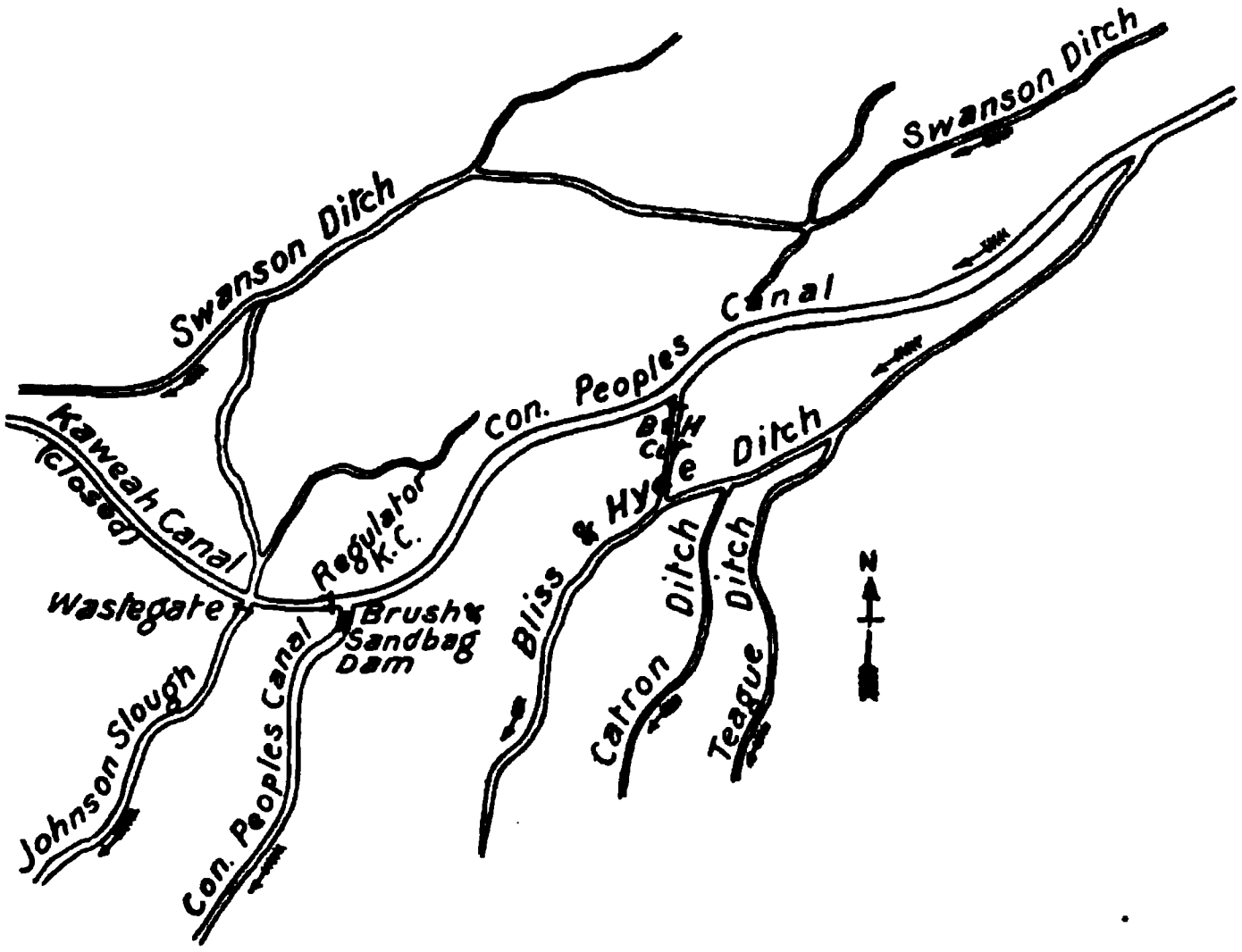


FIG. 5.—Ditch system at head of Kaweah Canal.

It is one of the canals whose successful operation was greatly interfered with by litigation. The canal was constructed in 1877. At that time the Fowler Cut was made for the Kaweah Canal and Irrigation Company, and led to the reestablishment of the original channel of Kaweah River, or of a new channel very nearly coincident with the original one in position. The agreement then made with the Consolidated Peoples Ditch Company gave the new company a right to use the upper sections of the Peoples Ditch for several miles, and below that point a canal was excavated, about 50 feet wide on the bottom and 3 feet deep, which temporarily dropped its water into Deep Creek, in which it flowed to within a few miles of Tulare. The main canal was soon afterwards extended across Deep Creek in a general southwesterly direc-

tion, passing about a mile to the west of Farmersville, until, at a point about 6 miles to the northeast of Tulare, it was separated into two main branches, of which the southerly one commanded the lands in the vicinity of Tulare, including the colony lands toward the west. The northerly branch was extended westerly across Cameron Creek to a connection with the Tulare Canal, and has irrigated a few tracts of land near Tagus. The total length of the main canal, not including the Fowler Cut or the Peoples Ditch, to where it separates into its two principal branches is about 10 miles. Irrigation from this canal has probably exceeded 4,000 acres. The canal was constructed by a corporation known as the Kaweah Canal and Irrigation Company, which was organized in 1877 by farmers who were in need of water for their lands in the vicinity of Tulare. The capital stock was fixed at $50,000, in 500 shares. The expense of canal construction and litigation soon exceeded this sum by at least $10,000. The canal always held its water for sale, but stockholders were entitled to receive it at slightly reduced rates. All expenses in excess of revenue derived from the sale of water were apportioned to stockholders. Water was not sold by measurement; it was delivered to the irrigators from the several canal branches in rotation, and was paid for at fixed rates per acre actually irrigated, generally $1 to $2 per acre. The right of the canal to receive any surplus waters from the Peoples Ditch was disputed in court by farmers who, as riparian owners on Outside Creek, demanded that all flow in the Peoples Ditch in excess of that required for that ditch should be wasted into channels leading into Outside Creek. Their claim having been sustained, the Kaweah Canal for many years received water only by sufferance and only during periods when the river afforded an abundant supply. Its water was no longer taken through the head of the Peoples Ditch, but a cut was made from Kaweah River below Deep Creek to the canal, and the upper half mile of Deep Creek itself was utilized as a source of supply. After the organization of the Tulare irrigation district the canal was sold to the district for $150,000, payment being made in bonds, but with the proviso that the stockholders of the Keweah Canal and Irrigation Company should be preferred takers of one-third of all the water entering the upper section of the canal, at the agreed price of $1.25 per acre per annum.

Farmers Canal.—This canal has its head on the east side of Deep Creek, about 2 miles below Farmersville. It has a southwesterly course, commanding several thousand acres of land between Elk Bayou and Deep Creek channels within 6 miles of the head of the canal. The bed width of the canal for several miles below its head is 14 feet. The head gate or regulator has a width of 18 feet. The water is turned from the creek into the head of the canal by means of a brush dam. The canal was constructed in 1875 by an incorporated company, whose members are the farmers using canal water. The capital stock was

fixed at $20,000, in shares of $100 each. The head of Deep Creek, from which diversion is made for this canal, is about 8 miles, in a direct line, above Visalia, on the south side of Kaweah River. No water flows into Deep Creek from the river during its low stages. Water is generally available from the beginning of March to the end of June. During this time a superintendent is employed to apportion the water to holders of stock. When the supply of water is limited it is used in turn by the irrigators. Each stockholder is permitted to sell or lease the water to which he is entitled. The water represented by a few shares of stock held in the name of the corporation itself is also subject to sale. The estimated cost of canal construction and expenses connected therewith is about $7,000 to $8,000. The annual assessment per share of stock for canal management and maintenance has been about $1. The structures necessary for a delivery of water into branch ditches are constructed and maintained at the expense of those who receive water through each.

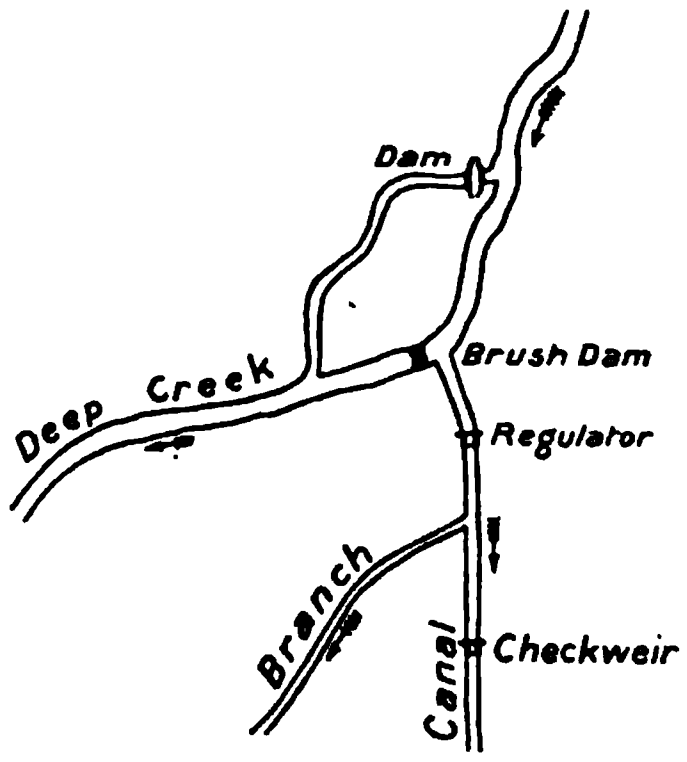


FIG. 6.—Head of Farmers Canal.

Tulare Canal.—This canal was constructed for the irrigation of lands in the vicinity of Tagus and to the northwest of Tulare. Its head is on the south side of Kaweah River, about midway between the head of Deep Creek and the head of Packwood Creek. It has a southwesterly course, is about 15 miles long, and has a bed width of 16 feet. The canal passes about 2½ miles to the south of Visalia and a mile to the south of Tagus, and terminates at the main canal of the Rocky Ford Canal Company. The canal was constructed in 1873. The farmers interested in the enterprise formed a corporation in the following year, known as the Tulare Irrigating Company, whose capital stock was fixed at $40,000, in shares of $100 each. The diversion of water from the river is accomplished by means of a dam or weir of brush, and the inflow into the canal is controlled by a regulator or head gate 16 feet wide. It has been claimed that the Ketchum Cut, one of the several ditches from St. Johns River southwesterly to Kaweah River above the head of the Tulare Canal, has been utilized by the Tulare Irrigating Company to accomplish the diversion of its water direct from St. Johns River, but it has not been possible to verify this claim, or to ascertain whether the canal company has any proprietary interest in the Ketchum Cut.

Before 1885 it was customary to apportion the flow of the canal to the stockholders in the corporation in proportion to their respective interests, but the holders of stock who were not ready to make profitable

A FLUME OVER TULARE CANAL, THE MAIN CANAL OF TULARE IRRIGATION DISTRICT.

B. MAIN CANAL OF TULARE IRRIGATION DISTRICT

use of their water demanded a change, and it was at that time decided to permit each stockholder to irrigate free of cost as many acres as he held shares of stock, and to charge $1 per acre for all additional areas.

Rocky Ford Ditch.—This ditch, now a part of the Tulare irrigation district canal system, takes its name from Rocky Ford on St. Johns River, because half a mile above is the head of the Ketchum Cut, which was bought by the Rocky Ford Canal and Irrigation Company, and was supposed to deliver water for the canal from St. Johns River into the Kaweah, from which it was reclaimed for the Rocky Ford Ditch at the head of Packwood Creek. The head of Packwood Creek, which had been almost obliterated by the freshets of 1861–62 and 1867–68, was reopened by this canal company in 1876. A cut 9 feet wide and three-quarters of a mile long, following the channel of Packwood Creek, received the canal water from Kaweah River. The water thus diverted was carried southwesterly in Packwood Creek, and in its south fork about 2½ miles, thence south in a ditch three-quarters of a mile to another natural channel, from which, a half mile below, it was dropped into Cameron Creek, which it followed, still in a general southwesterly direction, to a point about a mile south of Tagus. At that point the water was taken into a system of distributing ditches covering 4,000 to 5,000 acres of land to the southwest of Tagus, between Cameron and Packwood creeks. About $20,000 was expended on this work, besides $3,000 in litigation, but after a few years the company was deprived of the use of the Packwood Creek channel by an order of court, and those dependent upon this canal found themselves without water.

Cameron Creek Company.—This was an unincorporated organization of farmers which may be considered an offspring of the Rocky Ford Ditch Company. The purpose of the organization was to secure water for the Rocky Ford Canal, the head works of which were thrown out of service by orders of the court. There was ordinarily a surplus flow of water in the spring months, which reached Cameron Creek by way of the Deep Creek channels and the Kaweah and Tulare canals. The water thus reaching the Rocky Ford Canal from Cameron Creek was distributed to irrigators under the management and control of the Cameron Creek Company. The owners or lessees of stock in the Rocky Ford Canal Company were the preferred purchasers of water, but if there was sufficient available it was also sold to farmers who held no stock. The apportionment of water was by rotation in the use of the flow of distributaries. The time of use per share of stock was reduced as the supply decreased. The charge for water was at the rate of $1 per year per acre irrigated. The necessity for operations by this company ceased upon the completion of the canal system of the Tulare irrigation district.

Bacon & Crossmore Canal (Packwood Creek Canal).—When, in 1875, it became necessary to improve the flow of Packwood Creek for the supply of water to a large tract of land 6 to 9 miles west from Tulare,

a ditch was constructed from St. Johns River, then the principal channel of Kaweah River, commencing about a hundred yards above Rocky Ford, thence southwesterly about 4 miles, passing to the north and westward of a group of low hills known as the Swamp Angels, to a connection with the old channel of Kaweah River. Water thus turned into this channel was allowed to flow to a point in Visalia Creek about 1¼ miles below the head of Packwood Creek and was there diverted into a canal about 1,000 feet long leading southerly into Packwood Creek. These two ditches, or canals, together with the natural channel of Packwood Creek, are known as the Bacon & Crossmore Canal. The upper portion of this canal has a width of about 16 feet. The width of its head gate or regulator at St. Johns River is 40 feet. The cut for Visalia Creek into Packwood is about 30 feet wide. Its flow is controlled by a gate 30 feet in width. The point of discharge of the canal from St. Johns River into the Kaweah is just below Goads Dam at the head of the Tulare Canal. To enable diversion of water from Visalia Creek into the channel of Packwood Creek by way of the Bacon & Crossmore Cut, a brush dam is maintained in the creek about 60 feet below the head of the cut. The flow of Packwook Creek as thus established is first checked at a point about 4 miles west of Tagus, where distributaries are in use upon either side of the creek channel. Several other diversions are made some miles farther down the creek, and it is claimed that several thousand acres of land are irrigated by this ditch system.

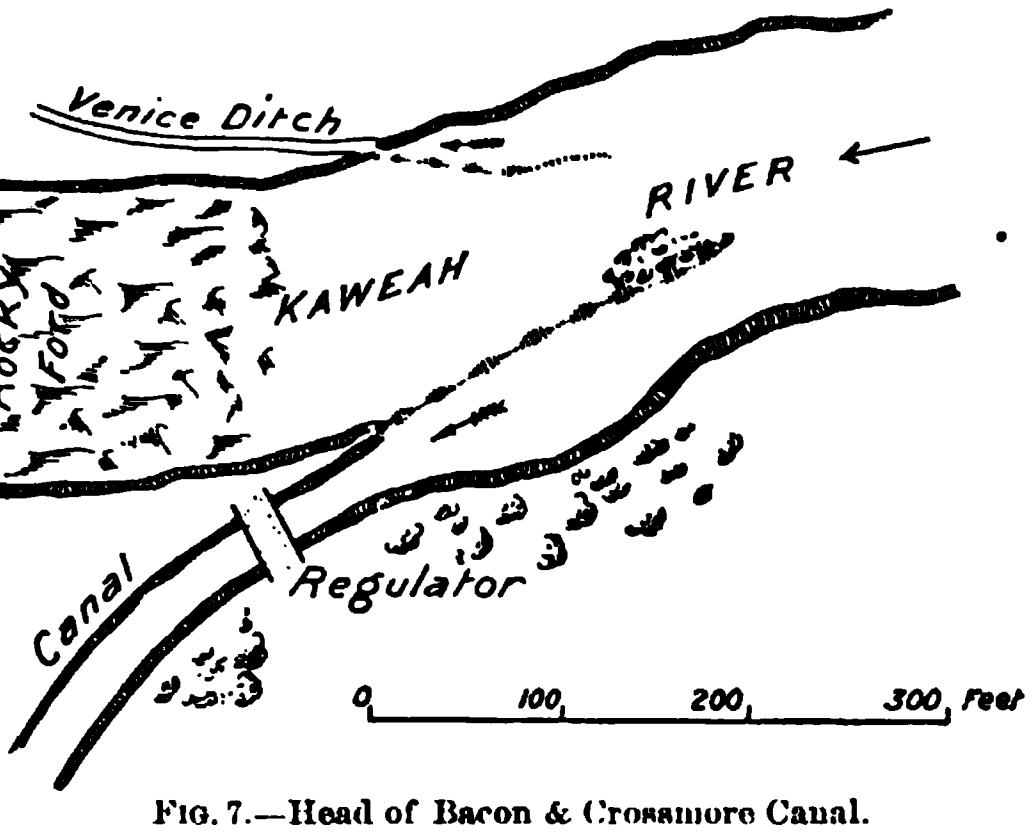


FIG. 7.—Head of Bacon & Crossmore Canal.

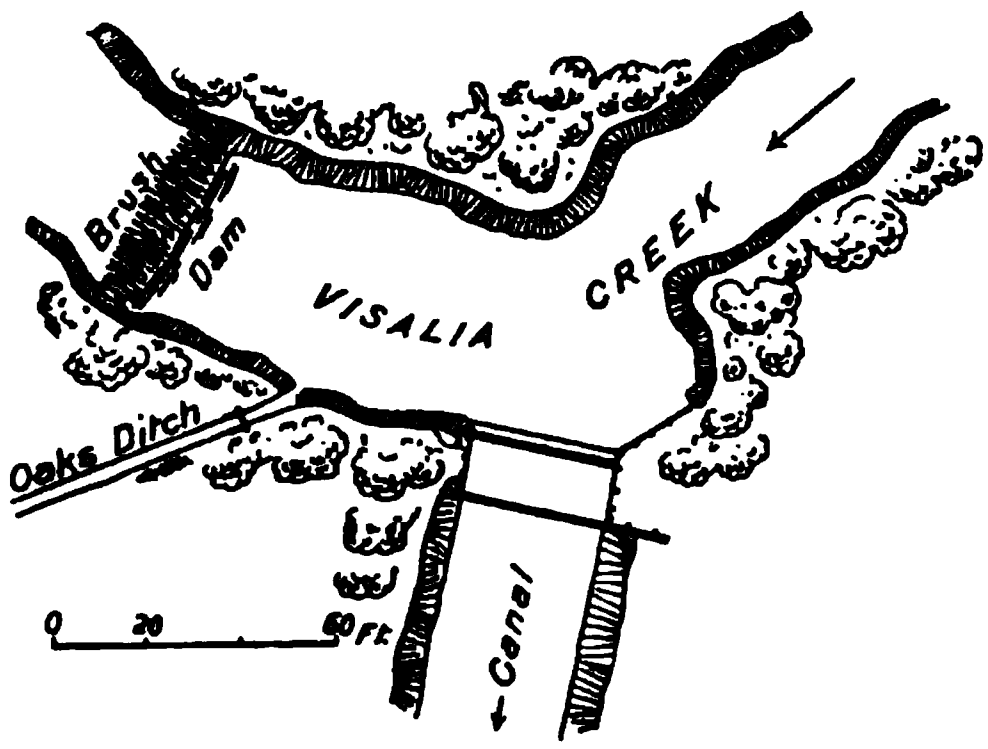


FIG. 8.—Head of Bacon & Crossmore Cut.

Judd Ditch.—This ditch was in use but a short time subsequent to the freshets of 1867–68. An organization of interested farmers known

as the Judd Ditch Company at that time endeavored to keep the head of Packwood Creek open, but owing to controversies with people living near Visalia on Visalia Creek the attempt was soon abandoned.

Cutler & Higgins Ditch (*Chatten Ditch*).—This is a small ditch between St. Johns River and Visalia Creek. Its head is on the north side of Kaweah River just above the point where it divides into the two channels, Visalia Creek and Packwood Creek. It has a westerly course, is about 2 miles long, 3 to 6 feet wide on the bottom, and belongs to several farmers, who take turns in using its water for the irrigation of a few hundred acres of alfalfa. The ditch has been in use since 1857.

Kaweah and Mill Creek Water Company.—This corporation was organized in 1877 with a capital stock of $10,000, in 200 shares, for the purpose of harmonizing and protecting conflicting interests by maintaining and controlling the flow of water in Mill Creek (Visalia Creek) and distributing it to the canals and ditches entitled to receive it. Its shares of stock were distributed to the owners of the various canals and ditches according to their relative interests, and the superintendent of this company is required to apportion the amount of water available to each ditch and canal in proportion to the number of shares of stock for which water is to be turned into each. A decision of the courts favoring the riparian doctrine has, however, made it difficult for ditch owners along Mill Creek below Visalia to reclaim their water, as the decision interferes with the construction of dams in the creek channel so long as they are objected to by riparian proprietors. To increase the flow of water in Visalia Creek it was found necessary to open the head of Lane Slough. This had been done before, but later freshets had again obstructed its channel near St. Johns River. The Bostwick Cut was the result of the work done by the company at that point. This is a canal leading southerly from St. Johns River, about a mile above Rocky Ford, into the main channel of Lane Slough. Lane Slough was one of the several natural channels having a southwesterly course through Visalia Swamp from near its northern margin to the old channel of Kaweah River above the head of Visalia Creek. It is claimed that this slough was so obstructed with drift and silt by the freshets of 1861–62 that for reclamation purposes it was necessary once before to open it, under direction of State authorities, with moneys from the swamp-land fund. The water company in 1878 also caused a section of the old channel of Kaweah River just below the head of Landers Slough to be reopened. The work there done resulted in the formation of the Hamilton Cut. All expenses of management incurred by the Kaweah and Mill Creek Water Company are raised by assessments levied upon the stock. The principal ditches dependent upon this organization for their water supply are the Oaks, Watson, Burch, Mill, Bahwell, and Fulgham ditches.

Oaks Ditch.—The head of the Oaks Ditch is on the south side of Visalia Creek, just above the dam maintained below the head of the Bacon & Crossmore Cut. It was in use prior to the organization of

the Kaweah and Mill Creek Water Company, from which it now receives its water. It is a small ditch, flowing several miles westerly between Visalia and Packwood creeks, and supplies water to seven or eight small farms. The entire flow of the ditch is usually divided into two irrigating heads.

Evans Ditch.—This ditch, which has also become dependent on the Kaweah and Mill Creek Water Company for its supply of water, has its head on the south side of Visalia Creek about 2 miles above Visalia. Its upper section serves as a common head for three otherwise independent ditches, the other two being the Burch and the Watson ditches. The Evans Ditch is entitled to one-half of the water entering its head, the Watson to one-third, and the Burch to one-sixth. The ditch has a southwesterly course, is about 5 miles long, and supplies water to about 500 acres just to the south of Visalia. Ownership in the ditch is represented by shares of stock, and the distribution of water is made in proportion to the number of shares of stock owned or controlled by each irrigator. Water is generally available for ten months each year, and is used in turn by the irrigators.

Evans & Turner Ditch.—This is a diversion from the west side of Packwood Creek about 2 miles below the Bacon & Crossmore Cut. It has a westerly course, is about a mile long, and drops its water into the Evans Ditch. It is claimed that this ditch was in use as early as 1858, but if so it was out of service for many years preceding its reestablishment, about 1884.

Burch Ditch.—This is another small ditch to which water is supplied under control of the Kaweah and Mill Creek Water Company. Although the ditch was in use before the organization of that company, and then received water direct from Visalia Creek, it has of late years been supplied with water through the head of the Evans Ditch. Its water, together with that for Watson Ditch, is turned out of the west side of Evans Ditch one-half mile below its head. It flows westerly three-quarters of a mile in a channel used in common with the Watson Ditch, and thence a little south of west to the southwestern portion of Visalia. It supplies a number of small farms southeast of Visalia. The head of the ditch was originally on the north side of the creek and its water was brought to the south side in a flume.

Watson Ditch.—This is another of the old irrigation ditches in whose interest the Kaweah and Mill Creek Water Company was organized. This ditch was constructed in 1854, before water was used by the mill in Visalia. Its head was on the south side of the creek about 3 miles east of Visalia, and its water was used near Visalia. It now receives water through a common head with the Evans and the Burch ditches, and is finally separated from the Burch Ditch water about a mile east of Visalia. Ownership in this ditch is represented by shares of stock, of which 100 may be issued. Between 60 and 70 are in the hands of fifteen to twenty farmers, who use its water mostly on small farms to the south and southwest of Visalia. It was originally intended that

each share of stock should represent 17.28 miner's inches of water (about one-third second-foot), and the original price per share was fixed at $5. Stockholders are assessed for all expenses of management and repairs. A superintendent is employed only when necessary, not when water is abundant, nor when there is none at all. Shares of stock not issued are not entitled to water. Holders of stock may sell or lease the water to which they are entitled. When the flow of the ditch is small it is given to the irrigators in turn for eight hours per share of stock. The annual expense of ditch management is about $5 per share.

Mill Ditch.—This is not an irrigation ditch, but it has rights to the use of water from Kaweah River, which make its enumeration among the Kaweah River ditches desirable. Its head is about one-half mile above Visalia, on the south side of Visalia Creek. It has a westerly course into the town, and drops its water back into the creek at the mill. It has been in use since 1854, at which time a brush dam was constructed at its head in Visalia Creek. This is another of the ditches in whose interest the Kaweah and Mill Creek Water Company was organized. The mill owners are stockholders in this corporation and receive the same consideration accorded to irrigators.

Bahwell and Fulgham ditches.—These are two small ditches below Visalia, which were included among those for whose benefit the Kaweah and Mill Creek Water Company was formed. They and a number of other small ditches make use of the freshet flow of Visalia Creek reaching the lower sections of Mill Creek, as well as of the water which is returned to the creek by the Mill Ditch.

Longs Canal.—This exists in name only. It was a canal or reopened slough constructed, some years after the freshets of 1861–62, southwesterly through the upper end of Visalia Swamp, from St. Johns River to Potter Slough, which discharged into Kaweah River. The first work done there was nominally for reclamation purposes—to facilitate drainage of the swamp. The canal was closed by the drift and silt brought down by the freshets of 1867–68, and was again opened at the expense of the Kaweah and Mill Creek Water Company.

Bostwick Cut.—This is a short ditch or canal, southwesterly from St. Johns River about three-quarters of a mile above Rocky Ford, to Lane Slough, which continues in a southwesterly direction to Kaweah River. It was constructed in 1863 or 1864, for drainage purposes, with money from the swamp-land funds. There seems to be no doubt, however, that it would not have been constructed had it not been desirable to increase the flow in Visalia and Packwood creeks for irrigation purposes. The cut was filled with drift and silt by subsequent freshets, and was again opened in 1876 by the same parties who the following year organized the Kaweah and Mill Creek Water Company. It is about 18 to 20 feet wide on the bottom and half a mile long. It is provided with a head gate having a width of 22 feet.

Ketchum Cut.—This is a ditch, about 8 feet wide on the bottom, having its head on the south side of St. Johns River about a half mile above Rocky Ford. Its course is thence southwesterly, skirting the eastern base of the Swamp Angels to Kaweah River, one-half mile above the head of the Tulare Canal. The ditch was constructed, probably about 1864, with money from the State swamp-land funds, ostensibly for drainage purposes. It was originally carried across Kaweah River. The right to use it for irrigation purposes has been claimed by the Rocky Ford Canal Company, and, possibly, also by the Tulare Irrigation Company. It seems to have been in use principally for the irrigation of a few small tracts of land on the north side of Kaweah River. Its flow is controlled by a head gate.

Crowley & Mehrtens Ditch.—To make the enumeration of the old irrigation works complete it is necessary to mention the Crowley & Mehrtens Ditch, which was a small ditch in use for some years on the south side of Kaweah River, westward from Wutchumna Hill. The head of the ditch was near the northwestern base of this hill. There is nothing left of it now except an old cut in rotten granite on the south bank of the river, just below where St. Johns River leaves the Kaweah.

TULARE IRRIGATION DISTRICT.

This district was organized in September, 1889, by landowners in the vicinity of Tulare. Those dependent upon the Rocky Ford Canal and Cameron Creek for their irrigation water seem to have been the prime movers in the matter of district organization. The lands dependent upon Packwood Creek (Bacon & Crossmore Canal) and upon the Kaweah Canal were mostly excluded from the district. The district has an area of 39,200 acres, including the 2,500 acres in the town site of Tulare. After much preliminary work, involving the examination and surveying of a number of feasible canal routes and reservoir sites for water storage, it was decided to purchase the water rights of the Settlers Ditch. This was done for $100,000, in district bonds, through an agent, who at the same time agreed to take an additional block of district bonds amounting to $50,000. The money realized from this bond sale was expended in constructing a canal, 60 feet wide on the bottom, from a point on the north side of St. Johns River about one-half mile below Rocky Ford in a southwesterly direction, nearly parallel with the river, about 2½ miles, to the southern base of Iron Mountain, where the canal water is carried across St. Johns River in a flume 9 feet wide and 4½ feet deep, which is supported by two bridge spans. The course of the canal from St. Johns River is a little west of south to Kaweah River, which is crossed in a similar flume. It then has a course due south to a junction with the Kaweah Canal. Before this entire canal section was completed the available $45,000 had been expended and the district was still without water. The Kaweah and Rocky Ford canals were purchased for $20,000. Contracts were let for the construction of

A CANAL REGULATOR AT KAWEAH RIVER, TULARE IRRIGATION DISTRICT

B. LATERAL, ONE MILE SOUTH OF TULARE.

lateral canals and for the enlargement and completion of the main canal, work being practically paid for in bonds which, it was understood, went to the contractor through a nominal purchaser. Main distributaries were carried through the district from northeast to southwest, and smaller ones, generally on land lines from north to south, completed the canal system. The aggregate length of district canals is said to exceed 150 miles, and the main canal capacity is given at 800 second-feet. It should also be said that the completed system of works involves the construction of a storage reservoir at Iron Mountain, to be supplied with water by means of a high-line canal with head somewhere near Dillons Point. The reservoir site has in part been purchased. The total bond issue by the district was $500,000, all of which has been disposed of.

The area of land irrigated in the district has been rapidly extended. It is said that from 5,500 to 30,000 acres, principally in alfalfa, cereals, and orchard, have actually been irrigated, the area varying within wide limits, according to amount and duration of the water supply. The inflow of water to the canal is controlled by means of three head gates or regulators, of which the one on the north side of St. Johns River is 60 feet wide, and each of the others 25 feet. They are all of the loose flashboard type, the several openings being about 4 feet, and the drop boards being supported by inclined timbers. A canal superintendent has general charge of water distribution, and he is assisted by ditch tenders. Water is generally available during the four months April to June, inclusive. Operating expenses are met by charging for water, the charge being fixed at 50 cents to $1 per acre for the first irrigation and half price for subsequent wettings. The charge in 1897 was 50 and 25 cents. The tax to meet interest on bonds and cost of its collection has been 1.85 to 1.90 per cent.

WATER SUPPLY, SOILS, AND METHODS OF IRRIGATION.

Prior to the great changes in channel alignment effected by the freshets of 1861–62, the Kaweah River waters spread at high stages over what was known as Visalia Swamp, which commenced at Wutchumna Hill and extended southwesterly about 9 miles, with a width of 1 to 3 miles. The spreading waters were reunited in various channels, as already explained, in and below this swamp. Channel capacity was inadequate to pass flood waters, not only in the swamp, but also below it. It was inexpensive to divert water from a natural channel, or even from a convenient spot in the swamp, into ditches, and the use of water for irrigation commenced soon after the arrival of the first settlers. A number of ditches were thus in use when the regimen of the river was changed by the freshets above mentioned, and entirely new works became necessary in some cases to keep the ditches supplied with water. It was some time before the magnitude of the changes in the river alignment and their ultimate effects were fully realized, and final

relief to those dependent upon the more southerly channels for water did not come until the old channel of Kaweah River was reopened as the Fowler Cut in 1877. Meanwhile there had been a continually increasing demand upon the several river channels for water, and almost every season at the close of the river's high stage there was contention and strife concerning the apportionment of the low-water flow to the different sections of Kaweah delta. Farmers who had settled on Canoe Creek, Elbow Creek, and Cross Creek had become accustomed to regard St. Johns Channel as the principal arm of the river, and dams for its diversion southward into and across Visalia Swamp were not tolerated without protest. When the low-water flow was finally restored to the old channel numerous attempts were made to force it back into St. Johns River, and amicable adjustment seemed out of the question. To avoid the possibility of having a permanent change made at the head of St. Johns River, land was there acquired by the principal south-side ditch companies. A brush dam was then tolerated in the Kaweah River channel, which effected a division of the flow at comparatively low stages, but the exact basis of water apportionment, if any had ever been agreed upon, is not known to the writer. After many years of individual effort some of the settlers were forced into cooperative measures, as already explained, with some degree of success. Had there been greater obstacles to overcome in securing control of water in the first instance, the development of irrigation might have been less rapid, but would probably have been ultimately effected with less friction.

The ditches and canals constructed for the reclamation of Visalia Swamp, as already referred to, were hardly necessary as drain ways, because the increased capacity given the river channels by the freshets of 1861–62 had greatly improved drainage, and they have in a measure become features of the irrigation system of this river.

The surface of the country watered by the many delta channels of Kaweah River has a slope from east to west of about 6 to 7 feet to the mile. The portion of it near Visalia and thence southwest to Tulare, which is generally known as the Four Creek country, is covered, in some places very densely, with a growth of majestic oaks. The soil in the upper portion of Visalia delta is a rich alluvial loam, generally sandy, sometimes heavy. Near the river the soil is deep, resting on sands or gravel. At the base of and between the outlying hills on each side of the river the predominating soil variety is a black loam or dry bog, containing much clay, sometimes gravel, and merges into the heavy red soil of the upper or eastern border of the valley plain. Under the soil of this plain a hardpan layer several feet thick is nearly everywhere found at depths of from 1 to 5 feet. Northward from Kaweah River this valley plain extends in a broad belt along the foothill base. The soil of this belt is of the usual heavy red variety, containing some gravel. Its surface is very generally besprinkled with the low mounds usually known in the West as hog-wallows. The ground water

of this north-side district is from 8 to 30 feet below the surface, depth increasing northward from the river and eastward toward the foothills. Westward from this high east-side plain, and still northward from the river-delta lands, the soil becomes shallower and alkaline salts abound in its surface layers. In the Mill Creek country, 4 or 5 miles westward from Visalia, the hardpan of the higher plain disappears, but the alkaline salts remain present in undesirable quantity.

The soils of the entire delta are generally sandy loams, chocolate colored, deep and strong, without the sublayers of hardpan that are characteristic of the plains. Ground water in the Kaweah (or Visalia) delta is usually at 8 to 12 feet below the surface. Near Tulare and westward from that town the soil is darker than in other portions of the delta. The surface of the soil throughout the delta is smooth and entirely free from the hog-wallows of the adjacent main valley uplands.

Intermediate between the Sierra Nevada foothills and Outside Creek, and southward from Kaweah River, is another belt of country, 3 to 10 miles wide, extending far southward toward Tule River and embracing many acres of excellent, rather heavy soil.

The light average annual rainfall in the Kaweah delta, only about 9 inches, the abundance of natural water courses, and the ease with which water can be diverted into ditches and kept under control, are circumstances which have combined to stimulate ditch and canal construction in this section of the State, but not for speculative purposes. The irrigation works are almost all owned by the farmers who need the water. There are but few irrigators who do not own stock in some ditch company. All irrigation canals in the delta have been carried in the most direct lines from source of water to place of use. They are almost invariably located on lines parallel with the main drainage lines of the country.

The lands watered by Kaweah River are utilized for diversified farming. The natural growth of trees and grasses has always been luxuriant to the limit of the overflow from the delta channels, and the construction of canals and ditches has greatly increased the wet area. Large areas are in use as natural pastures, particularly to the east and north of Visalia. Wheat still remains the staple farm product, but considerable areas have been planted to alfalfa, while the orchard and vineyard and the occasional truck patch give evidence of the rapid movement toward a more intense cultivation of the soil.

The aggregate capacity of the canals, ditches, and water courses whose flow is under the control of ditch companies will probably exceed 2,000 second-feet. There are fortunately many years in which for months at a time, and just when water is most needed, the flow of the river is in excess of this amount. It is difficult to approximate the area irrigated or benefited with water from Kaweah River, because in many instances water is not actually applied to the surface of the land, but reaches the soil indirectly through seepage. There is no way of collecting even imperfect statistics, however, except at great labor in

the field, so that when it is stated that about 50,000 acres are actually irrigated and an additional 40,000 acres are more or less directly benefited with water from this river, too great reliance should not be placed upon the statement.

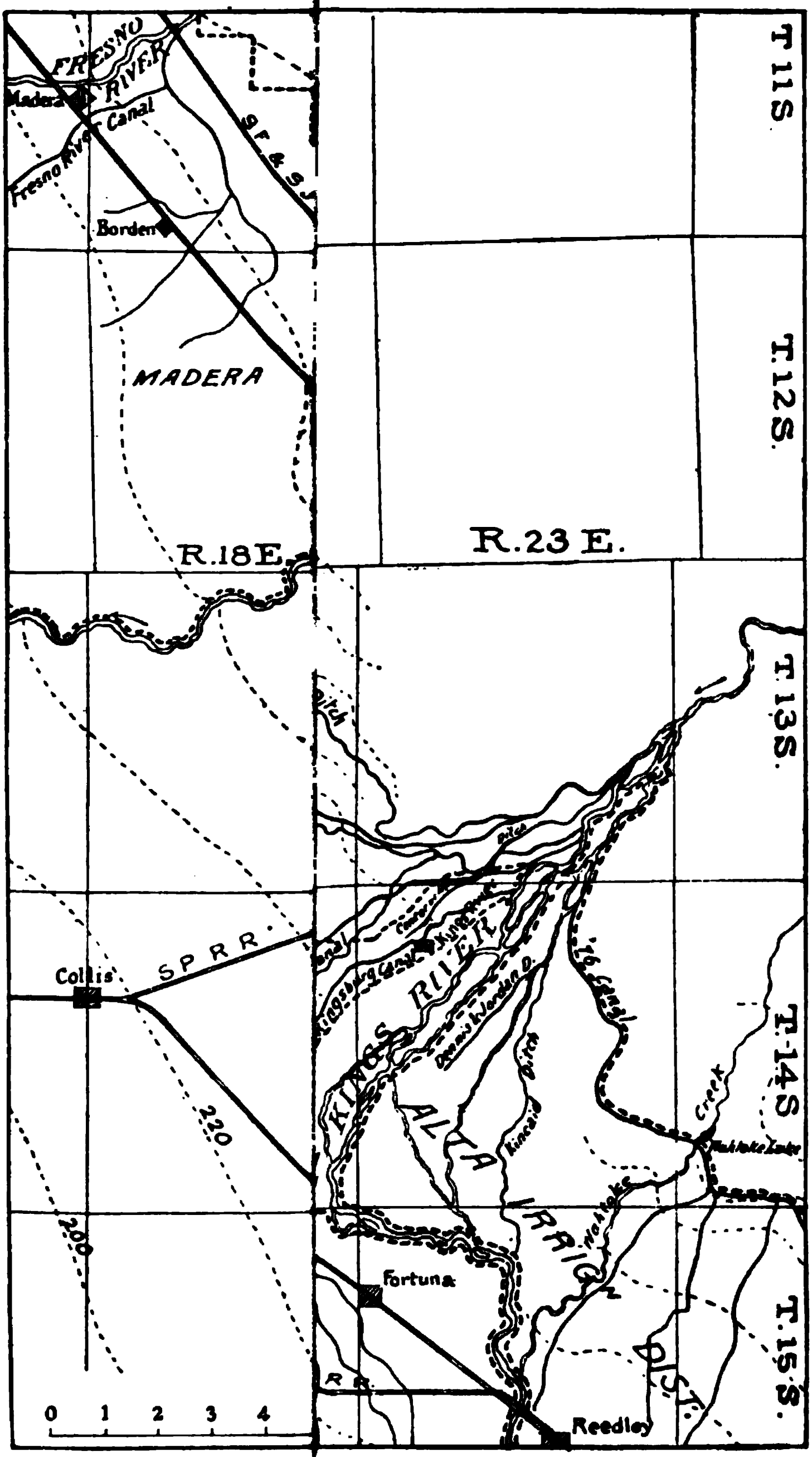
There are very few structures of any kind in the main canals, and but few are required to regulate the grade. Erosion is not undesirable, as the canals are generally long and water is taken from each at comparatively few points; hence the increased cost of providing weirs at points where water is to be diverted is more than offset by the increased capacity resulting from erosion.

All structures for the diversion of water, except dams at the heads of canals, are timber structures; none are of brick or stone. Dams across natural water courses are generally constructed of brush or gravel, and require some annual repairs. No extended observations have been made in this section to determine the loss of water from canals in transit to the lands irrigated; and it is to be remembered in this connection that not all water sinking into the ground from natural or artificial water courses is considered lost, because it is this very loss which fixes the elevation of the plane of subsurface or ground water, and the position of this ground-water plane often has a direct bearing on soil productiveness. Throughout a large part of the Visalia district ground water is within reach of the roots of trees, alfalfa, and other plants, being kept there by the water which sinks from natural and artificial channels in transit to lands irrigated and by the water which sinks into the ground on irrigated lands.

The method of applying water to the lands to be irrigated is generally by flooding, in small compartments or checks. These are adapted to the irregularities of the surface, being made rectangular when the surface is sufficiently level and smooth to permit of this arrangement. Crops cultivated in rows, such as beans, potatoes, and corn, also orchards and vineyards, are generally irrigated by running water in small ditches or furrows between rows. In the case of these products the soil is plowed or cultivated as soon after irrigation as practicable.

Here, as elsewhere in San Joaquin Valley, alfalfa is irrigated after each cutting (about every five or six weeks) so long as water is available. Orchards and vineyards receive water frequently during the spring months, and also in the summer if water holds out. Corn is irrigated once or twice, according to the condition of the ground at the time of planting. Grain is rarely irrigated; vegetables, very copiously and frequently.

No attention has as yet been paid to soil drainage. The many comparatively deep natural channels in the delta have kept ground water so far below the surface that the area in need of drainage is relatively small. As irrigation systems are further expanded throughout the delta it may be that subsurface soils will receive water more rapidly than it can pass off from them, and in such case improved drainage systems will become a necessity.


FRESNO RIVER
Madera
Fresno River Canal
SF & SJ
Borden
MADERA
R.18E.
R.23 E.
T.11S.
T.12S.
T.13S.
T.14S.
T.15S.
Collis
SPRR
220
200
Fortuna
Reedley
RR
0 1 2 3 4

KINGS RIVER.

HYDROGRAPHY.

The drainage basin of Kings River above the eastern margin of San Joaquin Valley has an area of 1,742 square miles. The river's watershed extends to the main summit of the Sierra Nevada. Less than half of it is to be classed as low mountainous, all the rest being high mountainous country. The snowfall of the winter melts but slowly during the spring months, consequently the river reaches its ordinary high period late in spring or early in summer. The river is generally low from September to the end of January; it is at a medium stage during February, March, and August, and is high from the beginning of April to the close of July. The month of least flow during the six years 1878–1884 was November,[1] the average mean flow having been 313 second-feet, and the least flow for a single month 220 second-feet. The extreme low-water flow of the river has, no doubt, been somewhat below the least monthly mean. At medium stages the river carries 1,000 to 2,000 second-feet of water; during its high stages its monthly mean ranges from 4,000 to over 8,000 second-feet. The maximum flow of the river during the six years above named occurred in June, 1884, the extreme limit having been about 30,000 second-feet.

A gaging station was established on this river September 3, 1895, by the United States Geological Survey. It is located abont 15 miles east of Sanger, 3 miles below Jarrett Ranch, and southwest of a hill well named Red Mountain. The station is equipped with a steel cable, car, and tagged wire.[2]

The results of these measurements show for the year 1896 a maximum discharge, which occurred in May, of 22,100 second-feet, and a minimum discharge, occurring in October, of 310 second-feet. The average discharge for that year was 2,582 second-feet. Similar figures for 1897 are as follows: Maximum discharge, 22,730 second-feet, occurring in May; minimum discharge, 250 second-feet, in September, with an average discharge for the year of 2,933 second-feet.

The Southern Pacific Railway Company has maintained gage-height readings at their bridge on the lower Kings River 1 mile from Kingsburg since 1879. The Geological Survey has taken a number of discharge measurements at this point, but owing to the shifting character of the stream it has been found impossible to construct rating tables for same.[3]

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[1] See Physical Data and Statistics, Wm. Ham. Hall, State Engineer of California, pp. 452, 476.

[2] Bull. U. S. Geol. Survey No. 140, 1896, p. 286; Eighteenth Ann. Rept., Part IV, 1897, p. 390; Water-Supply and Irrigation Paper No. 11, 1897, p. 92; Water-Supply and Irrigation Paper No. 16, 1898, p. 191.

[3] Twelfth Ann. Rept. U. S. Geol. Survey, Part II, 1891, p. 320, Pl. LXXXII; Bulletin No. 131, 1895, p. 80, Bulletin No. 140, 1896, p. 284; Eighteenth Ann. Rept., Part IV, 1897, p. 393; Water-Supply and Irrigation Paper No. 11, 1897, p. 920; Water-Supply and Irrigation Paper No. 16, 1898, p. 192.

Estimated monthly discharge of Kings River at Red Mountain, California.

[Drainage area, 1,742 square miles.]

Month.	Discharge (in second-feet).			Total (in acre-feet).	Run-off.	
	Maximum.	Minimum.	Mean.		Depth (in inches).	Second-feet per square mile.
1896.						
January	11,020	390	1,474	90,682	0.98	0.85
February	1,140	728	825	47,477	.51	.47
March	7,020	820	1,710	105,181	1.13	.98
April	4,600	820	1,938	115,349	1.24	1.11
May	22,100	1,140	5,918	363,890	3.90	3.40
June	18,920	5,160	12,737	757,922	8.15	7.31
July	6,680	1,212	3,742	230,110	2.48	2.15
August	1,212	590	795	48,938	.52	.45
September	590	390	491	29,234	.31	.28
October	510	310	350	21,520	.23	.20
November	1,076	390	538	32,043	.35	.31
December	550	470	466	28,659	.31	.27
The year	22,100	310	2,582	1,871,005	20.11	1.48
1897.						
January	624	360	437	26,870	0.29	0.25
February	6,344	1,100	1,631	90,581	.96	.92
March	4,408	1,240	1,884	115,843	1.22	1.06
April	9,380	1,930	5,318	316,442	3.33	2.99
May	22,732	6,344	14,470	889,731	9.40	8.15
June	10,580	2,520	6,145	365,652	3.87	3.45
July	4,040	1,036	2,177	133,859	1.41	1.22
August	1,100	440	739	45,440	.47	.42
September	480	250	329	19,577	.20	.18
October	572	270	394	24,226	.25	.22
November	2,520	360	692	41,177	.44	.39
December	8,348	572	985	60,566	.63	.55
The year	22,732	250	2,933	2,129,964	22.47	1.65

Kings River enters San Joaquin Valley from the east about 20 miles east of Fresno. Before reaching Centerville Bottoms the river flows in a broad bed of cobbles from which the hills rise quite abruptly toward the north and toward the south. The hills retreat from the river somewhat at the upper end of Centerville Bottoms, forming a wedge-shaped valley that opens into the main San Joaquin Valley about 4 miles farther west, at Centerville. The northern portion of this Kings River spur of San Joaquin Valley may be regarded as a second or upper

bottom; the southern portion, lying at a lower level, is the upper division of Centerville Bottoms. These bottom lands, which have a length of about 9 miles, are depressed below the general surface of the San Joaquin Valley plain, being about 10 feet lower than the same at their upper limit and about 60 feet below the same at the Narrows, where the main valley plain drops in abrupt bluffs to the banks of the river as it emerges from these bottoms at their southeastern extremity. From this point southward for about 12 miles the surface of the main valley has greater fall than the river, gradually approaching its level, and near Kingsburg the bluffs upon either side of the river entirely disappear. It is here that the Kings River delta begins.

Through Centerville Bottoms the river flows in numerous channels,

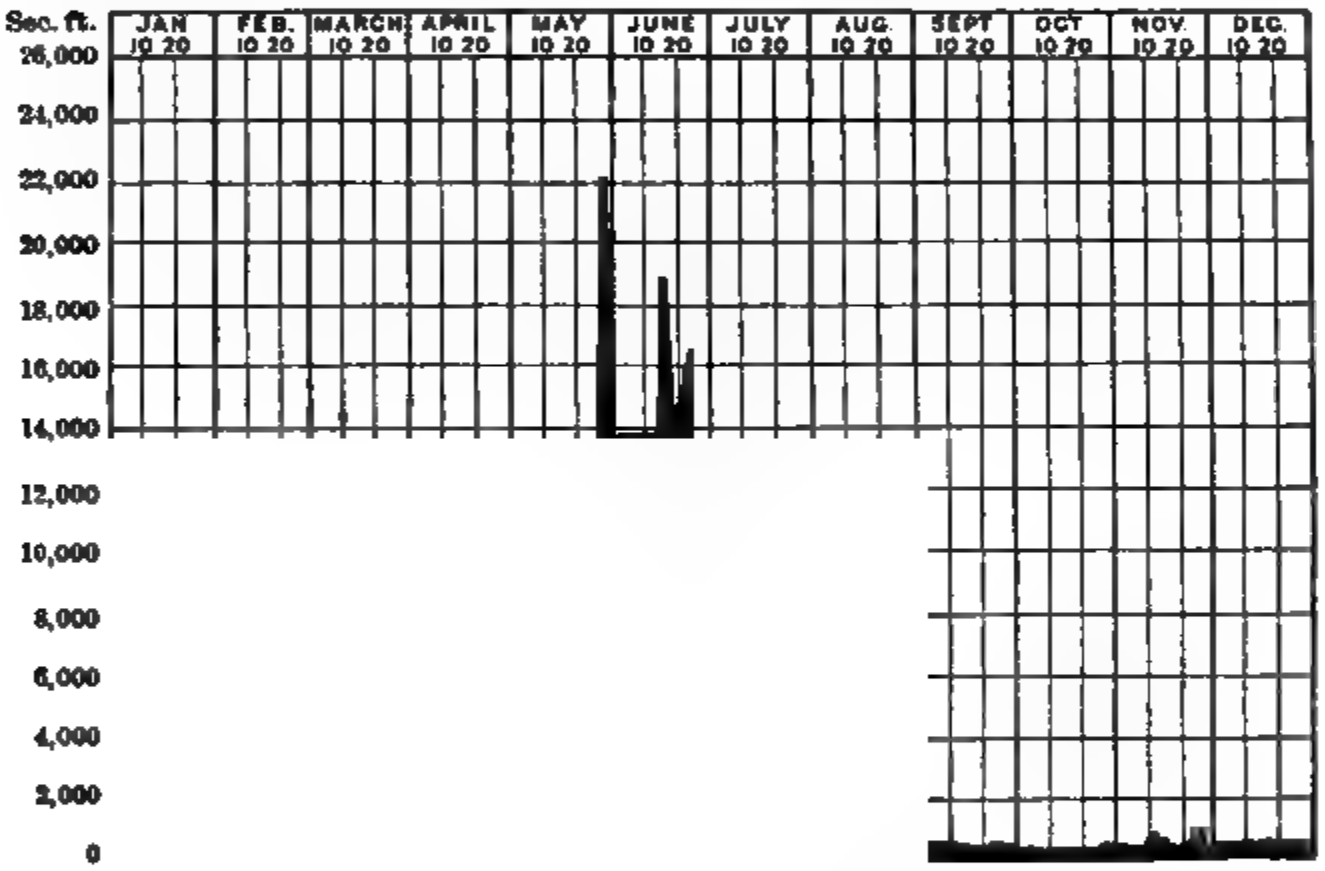


FIG. 9.—Discharge of Kings River at Red Mountain, California, 1896.

the main stream having a length of about 14 miles and a total fall in that distance of about 120 feet. The beds of these streams are for the most part formed of deposits of cobbles, gravel, and sand. Channel banks are rarely high or well defined. Below the Narrows the fall of the river is only 2 feet to the mile, which is maintained with reasonable uniformity to the outfall of the main channel into Tulare Lake.

From the head of Cole Slough, 2 miles south from Kingsburg, the main channel of Kings River has a southwesterly course for a distance of 35 miles to the trough of San Joaquin Valley; its course thence is south about 11 miles to Tulare Lake.

Cole Slough, the uppermost arm of the river thrown off toward the north, has a course nearly parallel with the main channel of the river for some miles, then flows northwesterly and, together with other delta

channels, delivers its water into Fresno Swamp, through which it flows into San Joaquin River. Kings River has but a single tributary below the point where it enters San Joaquin Valley. This is Wahtoke Creek, a small foothill stream which reaches the river from the east at the Narrows. Owing to scant rainfall, there is but little run-off from the lands of the plains, and this is, as a rule, away from the main stream and not toward it.

Canals and ditches from this river are to be divided into two principal groups, of which one embraces those which leave the river at the upper end of Centerville Bottoms and the other those of the delta. For convenience these groups may be again subdivided according to location of tracts irrigated, and will be treated under appropriate subheadings.

FIG. 10.—Head of Kings River & Fresno Canal.

CANALS AND DITCHES.

Kings River & Fresno Canal.—This is the upper north-side canal from Kings River. Its head is 5½ miles above Centerville. The canal receives water through the head of a natural channel or arm of the river which has a position at the base of the low north-side slope that rises from the border of the river bottoms. Within a mile of its head the canal is carried in a cut northwestward out upon the surface of the second bottom, and a half mile beyond its water is dropped into a small natural channel known as Burns Slough. After flowing in this southwesterly for a mile, the water is carried westward in a cut less than one-half mile in length to Kip Slough, from which it is again reclaimed 1½ miles below. The course of the canal, now in an artificial channel, is thence westerly across Fanshaw, Red Bank, and Frolic creeks into the Dry Creek district northeastward from Fresno.

The cut from Centerville Channel of Kings River to Burns Slough has a bed width of about 30 feet. Below that point the canal width is quite irregular, ranging from about 15 to 24 feet. The flumes over creeks are 16 feet wide, with sides 3 feet high. The longest one is that across Red Bank Creek, which has a length of 96 feet. The fall of the main canal is far in excess of what might be considered necessary, its course being almost in the direction of greatest fall of the ground's

KINGS RIVER AT UPPER END OF CENTERVILLE BOTTOMS, LOOKING UPSTREAM.

surface. This results in no injury to bank lands in the upper section of the canal, where a firm substratum sets a limit to erosion, but has made the use of frequent check weirs or drops necessary in its lower sections, particularly at points where water is delivered into branches.

The construction of this canal was commenced in 1872. At that time a regulator was placed in its head at Centerville Channel of Kings River. The following year the cut to Burns Slough was made and the canal was extended westward upon the valley plain. The canal was intended primarily to supply water to landowners who had become stockholders in it, but the sale of water was not restricted to the stockholders. The company's capital stock was fixed at $100,000, in 1,000 shares. Water is sold at rates annually determined, not exceeding $50 per second-foot for stockholders and $75 per second-foot for other irrigators. The sale of water covers all expenses of management and repairs. The first cost of the canal was about $50,000.

As a result of adverse claims to the use of Centerville Channel the canal company was in conflict with the Fresno Canal and Irrigation Company until, in 1875, it was agreed that the water in the regulator of the Kings River & Fresno Canal should be maintained at 1 foot in depth during the low-water period of the river until there was less than 1 foot in depth in the regulator of the other canal, and that thereafter equal depths should be maintained in both regulators.

The distribution of water to ditches of consumers is in charge of a canal superintendent. No system of measurement is in use. Water is delivered to each ditch on the judgment of the superintendent in proportion to the number of second-feet to which each ditch is entitled. No attempt is made to effect actual delivery of the amount of water bargained for. Any number of irrigators may unite and have the aggregate amount to which they are entitled delivered through one gate.

The Enterprise Ditch was the result of such combination of interests. It was constructed about 1885. It received water for a time from the main canal at the point where its waters are dropped into Kip Slough, and takes a westerly course along the base of the north-side foothills. Rounding the point of these about 2½ miles north of Centerville, its course is northerly for 4 miles, thence westerly about 8 miles, generally 3 to 4 miles north of the main canal. This ditch was, a few years after construction, sold to the Fresno Canal and Irrigation Company in consideration of 40 water rights that were issued to its owners.

Fresno Canal.—The head of Fresno Canal is about 1½ miles below the head of the Kings River & Fresno Canal; also on the north side of Centerville Channel. A short artificial channel having a westerly course drops the water of the canal into Chambers Slough, which is a depression at the base of the low bluff at the northern margin of the bottoms. This has been converted into a section of the canal by the construction of a levee along its south bank to a point a little over a

mile from the head of the canal. There the canal enters Long Cut, which extends westward in a direct line a little over one-half mile and carries the canal water into another natural channel, Burns Slough, which connects with Kip Slough a short distance below. Long or Big Cut pierces the rimland which borders Centerville Bottoms on the north. It has a greatest depth of about 10 feet and a width of 65 feet. Kip Slough is utilized for the canal for a little over a half mile. It is thence carried westerly nearly 2 miles in an irregular natural depression, which was converted into a canal by constructing embankments along the south bank of the proposed water way. From this depression an artificial channel only about 500 feet long drops the canal water

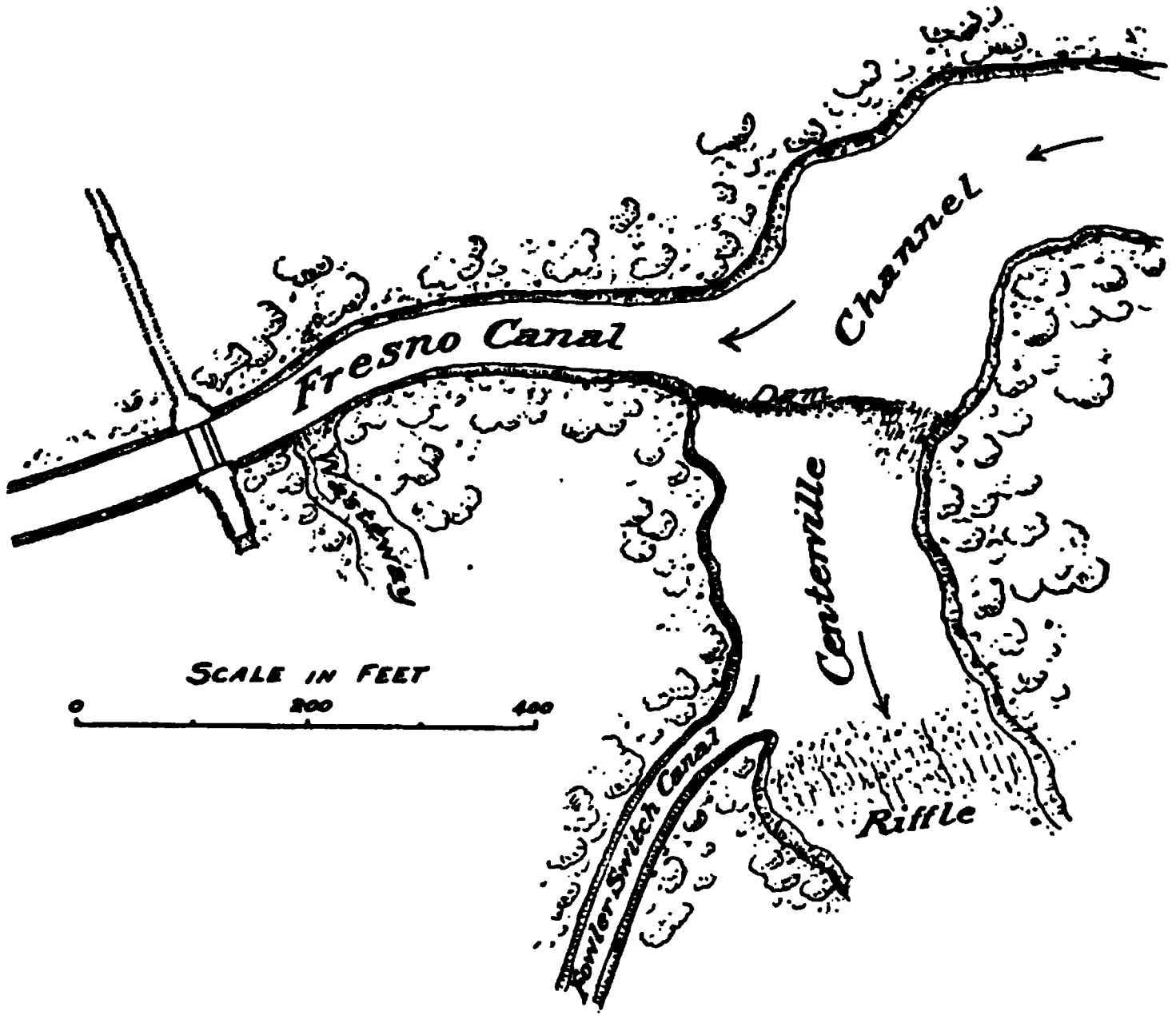


FIG. 11.—Head of Fresno Canal.

into Mud Creek, down which it flows in a southwesterly direction 3 to 4 miles to Fancher (Fanshaw) Creek, which then becomes the main channel of the creek to a point about 3 miles east of Fresno.

Where Fresno Canal leaves Kip or Lone Tree Slough the slough is closed by means of an embankment, in which a gate has been placed, through which water is delivered into the lower section of the slough, which is also known as the Kingsburg branch of Fresno Canal. This branch delivers water to the Highland, the Garfield (which also receives water from other sources), the McCall, and the Selma ditches.

The main canal may be regarded as terminating in the old sink of Fancher Creek, about 3 miles east of Fresno. From that point it sends southward its Washington Colony branch and southwestward

A REGULATOR ON KINGS RIVER AND FRESNO CANAL

B. FOWLER SWITCH CANAL NEAR SANGER, LOOKING UPSTREAM

the Central Colony branch, from which there is another branch to Fresno Colony. At the Hobler Dam, about 8 miles east of Fresno, a branch is taken out toward the south and reaches Fowler and the colonies in its vicinity, and another branch is carried westward from the north side of the main canal to portions of the Easterby ranches. Two miles above the Hobler Dam the principal north-side diversion is made. This is known as the Mill Ditch, which for many years furnished power to a flour mill in Fresno, and delivered the water, after use for power, to the colonies southwestward from Fresno. The ditch through Fresno and this north-side branch has become the feeder of the Bank Land Canal, which conveys water northwesterly to a large tract of land northwest of Fresno. Another north-side branch of the Fresno Canal is the Enterprise Ditch, which has already been referred to in describing the Kings River & Fresno Canal (p. 43). This ditch was purchased for 40 water rights.

No attempt will here be made to describe or even to enumerate the many small branches of this canal, particularly as some of these are owned independently and often receive water from other sources as well as from the Fresno Canal. It may be sufficient to state that the aggregate area covered by water rights (each nominally 1 second-foot to 160 acres) exceeds 160,000 acres.

The history of this canal construction is not without interest. Operations on it commenced in 1870 with the posting of a notice of a claim to water "to be taken from Kings River at the upper end of Sweem's Ditch, 20 feet on the bottom, 30 feet on the top, 4 feet deep." This claim was made by Mr. M. J. Church, who a month later acquired a two-thirds interest in the Sweem Ditch. The Sweem Ditch was a small ditch, the construction of which seems to have been commenced in 1870, which was intended to increase the flow of what was then known as the Centerville Ditch. Its upper section was enlarged and became the head section of Fresno Canal. In 1872 a regulator or head gate was constructed in the head of the Fresno Canal, and in the spring of 1874 a small cut on the line of the present Long Cut was completed from the Centerville Ditch to the lower sections of the Fresno Canal, on which work had meanwhile been pushed to the limit of the means of the projector of the work, Mr. M. J. Church. This small connecting ditch is reported to have had a bed width of only 5 feet on a grade of 5 feet to the mile. As the alignment of a part of the older Centerville Ditch was in time to become the alignment of a section of the Fresno Canal, and because it seemed desirable to secure the water rights acquired by the Centerville people, arrangements were made to obtain control of the corporation known as the Centerville Canal and Irrigation Company, and a transfer of their ditch property was made to the Fresno Canal and Irrigation Company. This was in 1874. As soon, however, as the settlers near Centerville realized what their officers were doing the demands for just treatment at the hands of the Fresno Canal and Irrigation Com-

pany were made so emphatic that those who were entitled to water in the older ditch were granted water rights in the new canal for their lands in perpetuity, without limit as to quantity and free from expense assessments. About 1,500 to 2,000 acres of land are thus covered. In 1875 it became necessary to enlarge the cut westward from the Centerville Ditch, and to this end labor was bargained for with farmers who wanted water delivered to their lands through Lone Tree Creek. Thirty-five water rights were issued to farmers, who completed it in June, 1875. Meanwhile other parties besides Mr. Church had become financially interested in the enterprise, notably Mr. P. Y. Easterby, and later Mr. W. S. Chapman. It was not profitable, however, at the outset, and, as the indirect result of overspeculation in wheat by outside parties and failure to increase loans, a transfer of the property in 1876 to the Bank of Nevada became necessary. The management of the property by this bank was expensive and gave no promise of success. It was not long, therefore, before the original projector of the enterprise was sent for and the property was sold to him, on the execution by him of a long-term note, for $28,000. By this time a number of large holdings of land had been subdivided and sold in small tracts and had become dependent upon the canal for water. Notable among these early colonies are Central Colony, 2,640 acres, and Temperance, Church, and Nevada colonies, each 640 acres. These colonies, together with the Pioneer vineyard on the F. T. Eisen tract, soon demonstrated the great productiveness of the Fresno sand plains, and the development of that region was rapid during the next decade. The sale of water rights had progressed steadily, so that in 1884 about 400 had been issued or bargained for, and their price had increased from $200 to $800 each. Later their price was fixed at $1,600 by the canal management.

A water right, as issued by the company, is the right to use one-thousandth part of the flow of the canal, not in excess of 1 second-foot, on a specified tract of 160 acres. The canal company reserves the privilege of issuing 1,000 water rights without enlarging the main canal. Each purchaser of a water right agrees not to use the water, or permit it to be used, on any other land than that for which the right is purchased, nor to permit the water to run off upon contiguous land or in any other way to run to useless waste, and he agrees to return surplus waters back into the main canal or a branch thereof. Each water right remains subject to an annual expense assessment, which ranges from $80 to $100. Water is delivered without any attempt at measurement to each irrigator at any point on the company's ditch system that he may select. No transfer of a water right can be made except with the land which it covers. Each purchaser of a water right grants to the canal company the right of way for ditch and canal purposes through any lands lying in the same township as the tract for which water is bought, and concedes to the company the right to use his private ditch provided the company does not use it so as to

COBBLESTONE AND BRUSH DAM OF FRESNO CANAL, KINGS RIVER

interfere with the delivery of his water. The purchaser of a water right further obligates himself to pay to the canal company annually an agreed sum (this has usually been $100), and in default of payment for thirty days to forfeit his water right. The water-right agreement further sets forth that the company shall not be responsible for deficiency in water supply caused by drought, insufficiency of water in the river, hostile diversion or obstruction, forcible measures or temporary damage by floods or other accidents, but that it shall use and employ all due diligence at all times in restoring and protecting the flow of water in its canals.

The structures on the canal do not deserve extended notice. They are all made of timber. The original regulator has been replaced by a second one, constructed about 1884, shown in Pl. VIII, *A* and *B*. It consists of a substantial framework of heavy timbers, spaces between vertical posts being closed by vertical sliding gates. From the head gate an embankment of cobblestones, gravel, and sand extends northward across Centerville Bottoms to a connection with high land, and prevents destruction of the upper section of the canal during freshets. The diversion of water into the head of the canal is effected by means of a brush-and-cobblestone dam, as shown in Pl. VII, the maintenance of which in the past has not been expensive. Along the line of the canal, wherever necessary to prevent excessive erosion, or where required to turn water into a branch ditch, light timber weirs are in use. Most of these consist of two side or bulkhead walls and a floor, usually placed a little below the grade of the canal, and a line of vertical posts supported by braces from below. Spaces between posts are closed to the desired height either by fixed horizontal boarding or by movable drop timbers or boards.

The impression which the whole work gives is that of haphazard management, the result of which is not, however, entirely unsatisfactory.

The control of the canal long ago passed out of the hands of Mr. Church, who effected a profitable sale of the property. It is now managed by parties who also own controlling interests in the Kings River and Fresno Canal Company and who have acquired the property known as Rancho Laguna de Tache. It remains to be added that these parties as owners of the rancho, which is located on lower Kings River, have entered into a contract with the Sunset irrigation district under the terms of which, in consideration of a reservoir site, a right of way for a canal, and a waiver of riparian rights, the irrigation district has paid to the owners of the rancho $250,000 in bonds and has agreed to make no demand for water until 3,500 second-feet of water are available for the Fresno Canal and the canal of the rancho.

Centerville Ditch.—This is at present a branch of the Fresno Canal. It was constructed in 1868 and 1869 by settlers near Centerville (now Kings River). They organized a company known as the Centerville

Canal and Irrigation Company, which was incorporated in August, 1868. This company seems to have been the successor in interest to all rights acquired by some of the settlers whose first steps to secure water were taken in 1865. The canal was constructed southwesterly from a point near where the head of the Kings River & Fresno Canal now is about 2½ miles to Burns Slough; thence this slough was utilized for about a mile to a point a short distance below the Long Cut, and thence the ditch was extended southwesterly about 3 miles farther to lands at and west of Centerville. The canal property was transferred to the Fresno Canal and Irrigation Company in 1874, by those who had secured control of the stock, and the opposing minority interests were finally placated by the issuance of perpetual, unassessable water rights in the newer canal to stockholders who owned lands near Centerville.

Sweem Ditch.—This ditch was never completed. Its construction was commenced in 1870 from a point near the present head of the Fresno Canal, practically on the alignment subsequently adopted for that canal. Its purpose was to increase the delivery of water into Burns Slough for the Centerville Ditch. It was sold before completion to the parties who were at work on the Fresno Canal project, and within a few years it was transformed into a large canal, as already explained.

Fowler Switch Canal.—The head of the Fowler Switch Canal is in Centerville Bottoms, about 100 yards below the head of the Fresno Canal. Its course is southwesterly for 1½ miles in Centerville Bottoms, thence westerly for 2 miles across the second bottoms to near the channel of Lone Tree Creek, thence southwesterly 10 miles and southerly 5 miles to a point about midway between Fowler and Selma, thence southwesterly 5 miles, thence northwesterly into the district southward from the Washington Colony. The canal is said to have been built to carry 1,500 second-feet. Its bed width is about 45 feet, its depth variable. The gradient is very irregular, being that of the natural surface of the ground in its upper sections, where a quite firm hardpan formation is relied upon to check excessive erosion of the canal bed. Near the lower end of the canal it was given a fall of 1.92 feet to the mile.

It was proposed to use no check weirs to reduce the fall, which for short distances was as great as 12 feet to the mile, and to put lateral ditches at a lower elevation than the main canal, so as to reduce the necessary structures to a minimum. It was soon found, however, that weirs would be necessary at some points to check erosion and at most points where water was to be diverted.

Among the branches of the Fowler Switch Canal may be mentioned the Cleveland Ditch, about 5 miles long, which delivers water to lands midway between Malaga and Fowler; the Western Canal, which supplies water to lands adjacent to and immediately south of the Sierra

A. REGULATOR OF FRESNO CANAL ON KINGS RIVER, AS SEEN FROM ABOVE

B. REGULATOR OF FRESNO CANAL ON KINGS RIVER, AS SEEN FROM BELOW

Park and Washington Colony; the Grant Ditch, which has a westerly course for 4 or 5 miles from near the end of the main canal; and the Elkhorn Canal, which has a southwesterly course and delivers water to the western portion of the Wildflower region. The entire canal system gave promise of being one of considerable importance to the prosperity of the district it commanded, but hopes have not been fully realized. The canal has not been permitted to take river water without protest, and unfavorable court decisions have thrown some doubt upon the reliability of this canal as a source of supply.

This canal was constructed in 1883. Farmers in the vicinity of Fowler who wanted water for their own lands formed a corporation,

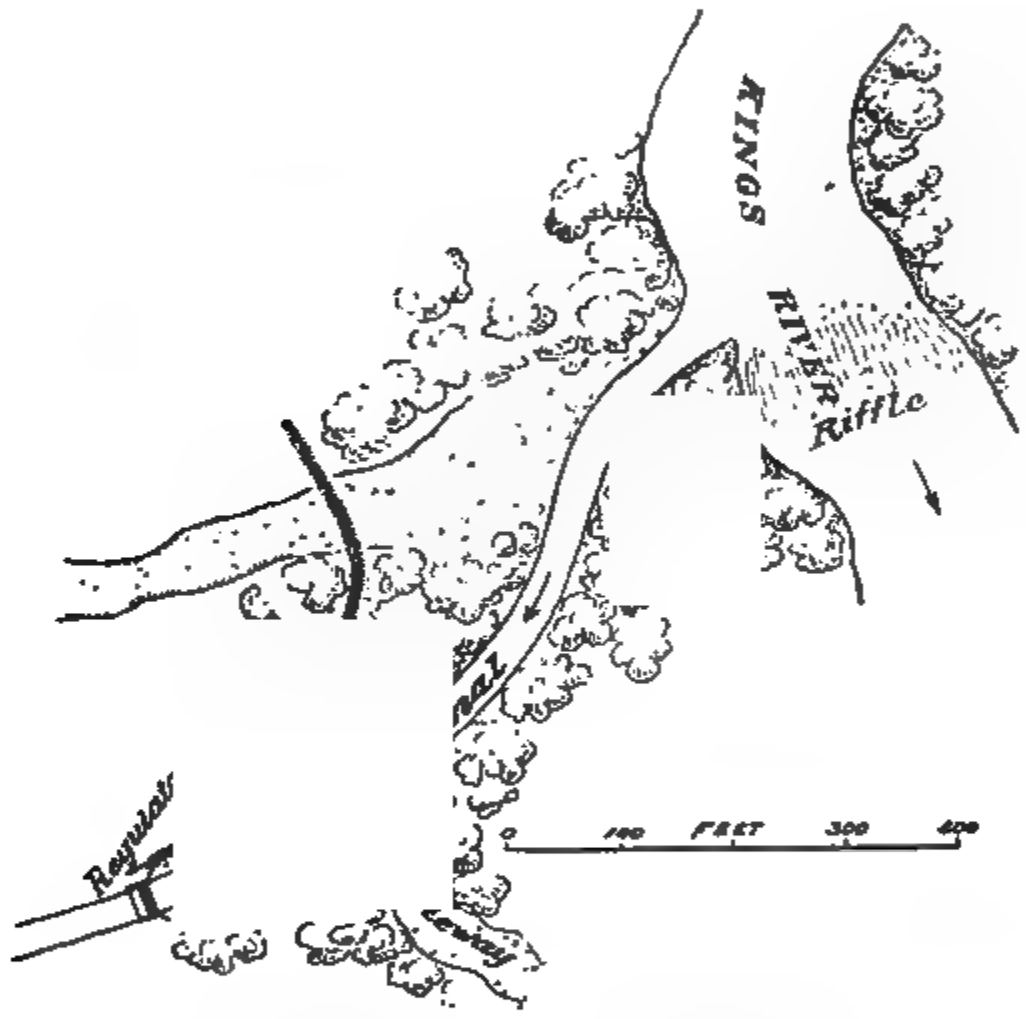


FIG. 12.—Head of Fowler Switch Canal.

the capital stock of which was fixed at $450,000, divided into 1,500 shares, of which 300 were subscribed for. It was agreed that in payment for each share labor and material might be contributed to the extent of $200, the remainder to be paid in coin. It was soon found, however, that the first issue of shares would not cover the cost of canal construction, and it was followed by a second issue of 300 shares, which were taken by the same persons who held the first issue. About $110,000 were expended on canal construction in the first two years.

The water in the canal is apportioned to the stockholders, who may ask for the delivery of their water at any point on the main canal. This has led to the construction of a number of branch ditches under

independent management, which receive their water from the main canal. One of the principal branches of this sort is the Elkhorn Ditch. It is owned by a company in which thirty shares are represented. Some of the stockholders in the Elkhorn Ditch Company are not holders of Fowler Switch stock. In such cases they are required to buy their water from some stockholder. The use of the Elkhorn Ditch is restricted to its owners, no water being sold.

The water represented by the stock of the Fowler Switch Canal Company is at the disposal of the individual stockholders to the extent that it may be leased or sold and its delivery may be called for through any branch ditch. No system of water measurement or special design of gate has been prescribed. All gates in distributing ditches are constructed by the consumers. The delivery of water through these gates is in charge of a canal superintendent. The canal company itself does not sell any water. All expenses are met by assessing the stockholders.

The structures on the canal do not merit extended notice. They are all of very light construction. The check weirs or drops are V-shaped, upper and lower faces being permanently sheathed with light boarding. There is no diverting dam at the head of the canal, which has been located just above a natural cobblestone-and-bowlder riffle.

Centerville & Kingsburg Canal.—This is another of the important north-side canals from Kings River belonging to the upper group of canals. Its head is about 2 miles in a direct line northeast of Centerville, and about the same distance by river below the head of the Fowler Switch Canal. Its course is westerly for nearly half a mile, directly toward the northwestern margin of Centerville Bottoms. Its second half mile has a southwesterly direction, along the slope from higher plains to the bottoms; thence on the higher level it holds a course southwesterly and southerly for about 8 miles, practically parallel with the bluff, 20 to 30 feet high, which drops from the valley plain to Centerville Bottoms. This portion of the canal is frequently within a few rods of the edge of the bluff, and is rarely more than half a mile distant therefrom.

About 9 miles below its head the canal is separated into a number of branches, which radiate throughout the district westward from Kings River below the Narrows, extending southeastward to lands east and south of Sanders, southward to the vicinity of Kingsburg, and southwestward beyond Selma and well into the Wildflower country.

The main canal has irregular dimensions, its bed width being generally about 30 to 35 feet. It has been allowed to cut deep into the friable surface soils in the upper sections of its course, where but little attempt has been made to reduce its gradient below that of the natural surface of the ground. The length of main canal is about 18 miles. The length of its three principal branches is reported at about 26 miles.

The diversion from the river is effected by means of a brush-and-cobblestone dam, in which a small gate serves as waste way and sand

A REGULATOR ON FOWLER SWITCH CANAL, AS SEEN FROM ABOVE.

B. REGULATOR ON FOWLER SWITCH CANAL, AS SEEN FROM BELOW

sluice. The canal regulator is close to the river and is of a type very common on Kings River canals. Three rows of posts rising from a plank floor extend across the canal from one bulkhead wall to the other. They support a platform loaded with cobbles and gravel to give stability to the structure. The spaces between upper posts are closed by means of vertically sliding gates, each of which has a stem extending above the platform, to which power is applied when the gate is to be opened or closed. The cost of the regulator was about $1,000. The first cost of the canal was about $35,000.

This canal was constructed in 1877 and 1878. It was built by a company organized by farmers who owned lands near Kingsburg and Selma. The capital stock of the corporation which they formed was originally fixed at $12,500, but was subsequently increased to $35,000, being divided into fifty shares. The upper 2 miles of the canal were constructed by day labor. The rest of the main canal was divided into

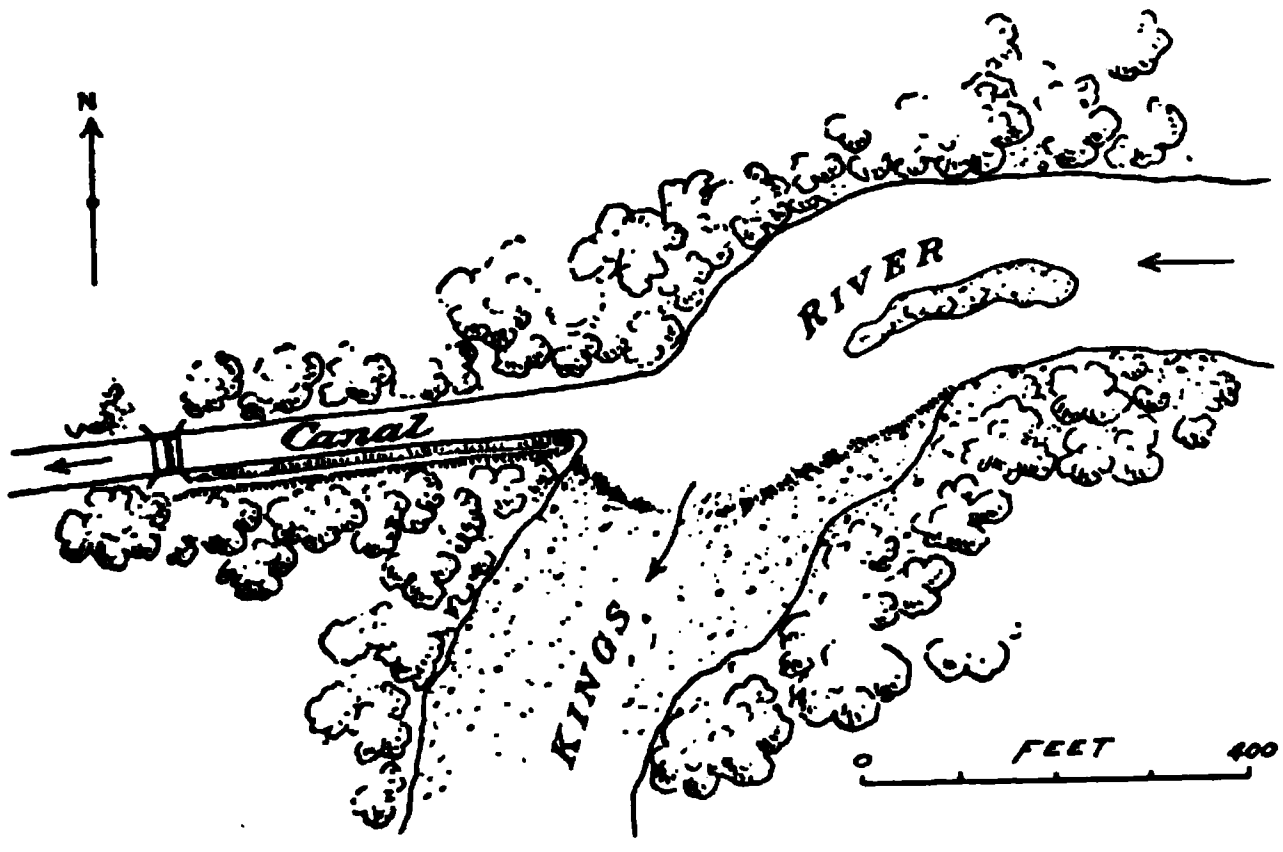


FIG. 13.—Head of Centerville & Kingsburg Canal.

sections, each of which represented one share of stock, and was assigned to some stockholder, who was required to complete it. A few unlimited, unassessable rights to water from the canal have been granted to settlers near Centerville, in consideration of rights of way. Each stockholder is entitled to the delivery of a proportional part of the water remaining available for distribution; but each stockholder, or the corporation when in possession of any shares of stock, may lease the shares. The price of a share per month in 1882 was $6. Shares were at that time valued at about $1,500. Each share of stock is supposed to represent "3 feet of water;" an expression of quantity which seems as vague as the amount named in the franchise of the company—"150 cubic feet of water under a 4-inch pressure." In fact, however, each share of stock entitles its holder to a proportional part of the water varying somewhat according to the number of shares in actual use, but not in excess of three times the amount which would flow 4 inches deep

over a clear overfall 12 inches long. Water is apportioned on the judgment of a canal superintendent, generally through gates of like construction. When the amount of water per share of stock in the canal exceeds three units, each indicated by a clear overfall of 4 inches on a length of 12 inches, then all surplus water is held for sale, by the directors of the company, at fixed rates per month per unit. The cost of canal management, maintenance, and repairs is assessed upon the stockholders. The annual expense assessment is now about $80 per share of stock. The works required to divert water from the main canal into private ditches, including weirs in the main canal, are constructed by the consumers of water, subject to approval of the canal company.

Satisfactory use of this canal has been interfered with to no little extent by litigation, generally involving the right of the canal to receive water from the river, and, as in the case of other canals from Kings River, its permanent efficiency as a source of supply has been thrown somewhat into doubt by adverse decisions of the courts.

Selma irrigation district.—This irrigation district is situated on the north side of Kings River, in Fresno County, and embraces within its limits the lands now watered by the Fowler Switch and the Centerville & Kingsburg canals. It was organized in 1890 with an area of 271,000 acres. For the purchase of existing canals and the construction of new works, it was proposed to issue bonds to the amount of $1,000,000; but the bond issue was twice defeated at the polls, and it seems to be generally conceded that there is small probability of a continuation of operations under the district law.

Alta irrigation district (76 Canal).—The canal which supplies water to the Alta irrigation district is known as the 76 Canal. It belongs to the upper group of Kings River canals. Its head is on the south side of the river, about 1½ miles above the head of the Kings River & Fresno Canal, if the point at which the uppermost work for the direction of water toward the canal regulator may be termed its head. At that point a branch of the river has been enlarged somewhat and otherwise improved, and the water diverted from the main stream through this natural channel is carried in a succession of depressions or high-water channels along the southeastern margin of Centerville Bottoms about 3 miles, to the point where the canal cuts out upon the higher plain lying to the east of Centerville Bottoms. The natural depressions of the upper coal section have in large part been converted into a canal by building up, along their low western banks, embankments of cobblestones and bowlders, which were taken from their beds for their enlargement. Where the canal turns away from Centerville Bottoms a cut 9 feet in depth was necessary. From this point the canal has a general southeasterly course, following a grade line with 18 inches fall to the mile, that skirts the western foothill base. At 6 miles below the regulator the canal is carried across Wahtoke Creek, and its southeasterly

A. REGULATOR ON SEVENTY-SIX CANAL, AS SEEN FROM ABOVE.

B REGULATOR ON SEVENTY-SIX CANAL, AS SEEN FROM BELOW

course is maintained about [illegible] miles [illegible]. The main canal has been made the eastern [illegible] gation district.

The bed width of the canal throughout the first [illegible] miles below the regulator is 100 feet. Its capacity, with a depth of [illegible] feet of water, is about 1,200 second feet. From the main canal numerous branches extend southwesterly and southerly into the heart of the district. The principal of these is the Traver branch, which has been given a bed width of 60 feet. It leaves the main canal about [illegible] miles below Wahtoke Creek, and, as its name indicates, delivers water to lands in the vicinity of Traver. Branch canals are for the most part located across the valley plain on lines of its greatest slope. They have generally been given positions on high ground, intermediate between gentle depressions, though in some instances, as in the case of the Traver

FIG. [illegible].—Wahtoke Reservoir, on W. Canal.

branch, natural water courses have been in large part substituted for expensive canal work.

The inflow of water from the upper canal section into the second section of the main canal is controlled by means of a regulator or head gate. Above the regulator in the west canal bank is a spillway through which surplus waters are dropped into Patterson Slough, one of the Kings River channels in Centerville Bottoms. The regulator rises from a plank floor constructed of two layers of [illegible] planking, the dimensions of which are 100 feet in the direction across the canal by [illegible] axis. The surface of the floor is at grade of the canal bottom. Along its upper and lower edges are two lines of sheet piling [illegible] constructed in trenches, which extend to a depth of 5 feet. The bottom ends of the sheeting planks are nailed to [illegible] inches, which adds to the effectiveness of the sheeting. Trenches were

refilled with carefully selected material well tamped into place. Three rows of posts, with necessary brace timbers, rise from this floor, the post rows being 8 feet apart. They support a platform which serves as a bridge. Between the upper posts are the gates, twenty in all, which slide vertically in grooves formed by spiking additional timbers to the upper faces of the posts. Each gate has a stem to which power is applied by means of a lever. Every fourth gate is provided with two vertical revolving shutters, so connected with it that when closed they will not interfere with the free movement of the gate. These shutters are intended to be used when the water pressure on the gates is so great as to interfere with their being raised. The cost of the head gate was $3,000. Lumber at the gate costs $28 per thousand feet, board measure. About 60,000 feet of lumber were used in its construc-

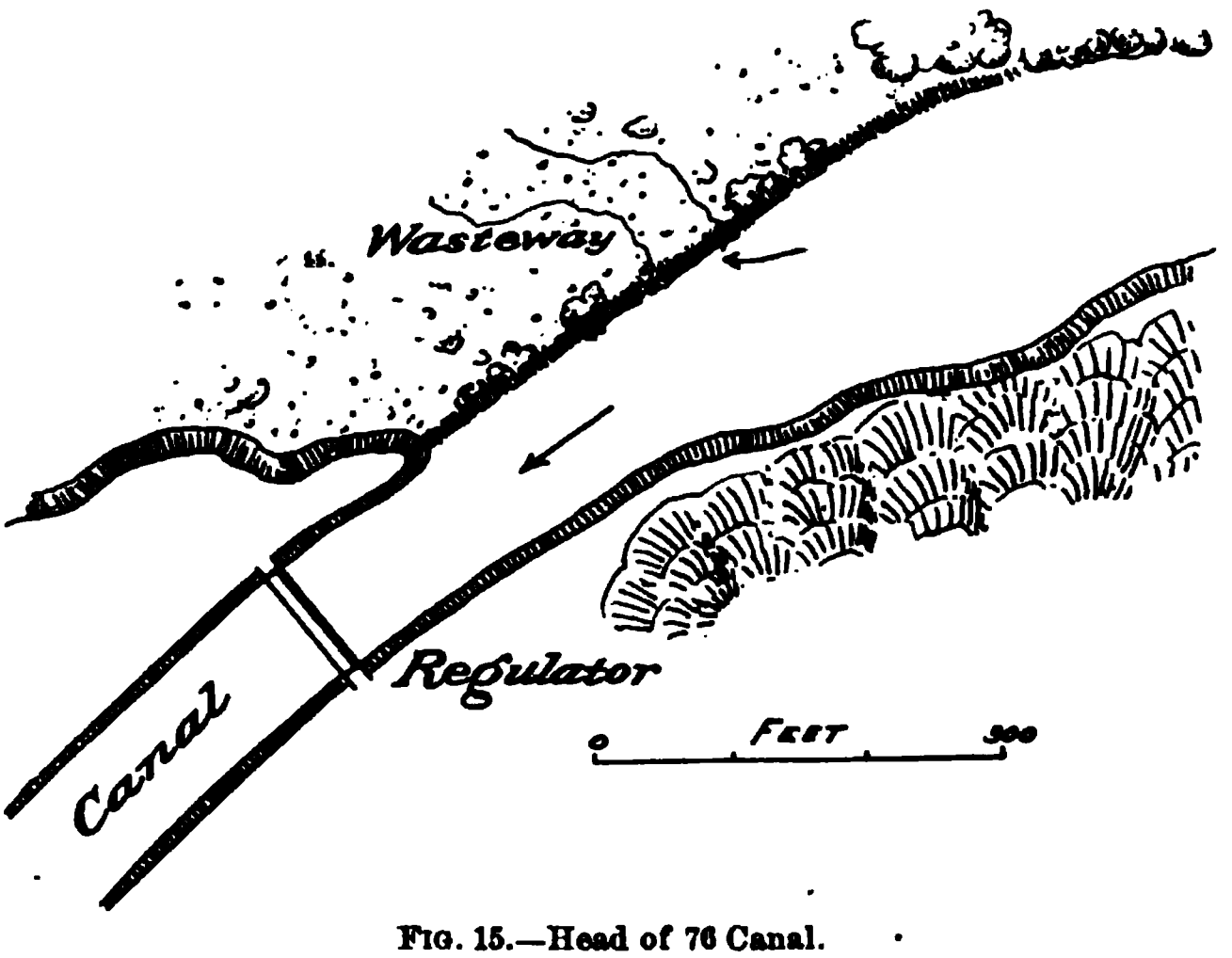


FIG. 15.—Head of 76 Canal.

tion. The check weirs in use on this canal system (there are nine on the Traver branch within 7½ miles above Traver) are simple but serviceable structures. They are of the flashboard type. Spaces between posts 4 feet apart, which rise from a plank floor, are closed by loose boards sliding in grooves. The cost of a check weir across a canal 60 feet wide is reported to have been $275.

Occasionally a firm hardpan layer that would not yield readily to blasting or plowing had to be broken up into long, narrow strips with gads. A spur of rotten granite was crossed at one point, and the maximum cut through it was 28 feet. Throughout 5 miles below the regulator large cobbles—some 1 foot in least diameter—had to be removed from the material loosened by the plow before scraper work could commence. The ground containing these cobbles was first trenched with large road plows drawn by 12 to 16 mules. The plows were steadied by means of long saplings extending out on either side.

Along the base of Campbells Mountain, throughout the 3 or 4 miles above Wahtoke Creek, the surface soil into which the canal was cut is dry bog—a dark-colored, light soil, which contracts, cracks, and crumbles in drying. When wet this soil is soft and sticky. This material had to be used in many places for the canal embankment, which often crossed depressions, and when water reached these it rapidly permeated the spongy bank and often found vents that led to the speedy destruction of the embankment. It cost about $6,000 to get the water in the canal as far as Wahtoke Creek.

The canal was constructed in 1882. This was before the enactment of the irrigation-district law. Its construction was undertaken by a private corporation, on a plan which was very satisfactorily carried out. As soon as the feasibility of making the diversion of water from the river was assured, about 40,000 acres of land on the plains to be commanded by the canal were bought for the corporation at prices less than $10 per acre. These lands were offered for sale as soon as the canal came into service, at prices somewhat in excess of the added cost of canal construction. It was proposed to establish each year a schedule of prices to be adhered to for a year, but demand for land was so great at the prices fixed during the first few years that the lands were

FIG. 16.—Plan and elevation of regulator for 76 Canal.

repeatedly withdrawn from sale. The expenditure of less than $300,000 in four years thus created and increased values to an estimated amount of over $800,000, not including increased values of properties in which the canal company had no direct interest.

Before the canal was sold to the Alta irrigation district, water rights were issued to purchasers of all lands sold by the canal company and were for sale to others owning land in the district commanded. A water right was defined as 40 miner's inches of water, and was located upon some particular 40-acre tract of land, of which it became an appurtenance. Each full water right was made liable to an assessment of $16 per year to cover expenses of canal management. The price of a water right was fixed at $200.

The Alta irrigation district was formed in 1888 and was made to include the lands to be irrigated with the 76 Canal. It extends southerly from Kings River to and even beyond Cottonwood Creek and westerly to within a mile of the eastern border of the Kings River delta, and has an area of 130,000 acres. Two years later the district purchased the canal and its branches, paying therefor $410,000 in bonds of the district. This covered the repayment to holders of water rights of the amounts which they had paid for them.

The northern apex of the Alta irrigation district is at the western base of Tchoenimne Mountain, where a second river bottom, 10 to 20 feet higher than Centerville Bottoms, lies below the 76 Canal. From the second bottom, which is long and narrow, having an area of nearly 7,000 acres, there is an abrupt rise of 20 to 35 feet to the upland or main east-side San Joaquin Valley plain. The surface of this plain drops away gently from the base of the hills southwestward toward the valley trough. Its slope is at first about 10 feet to the mile, but this becomes gradually less and is only 6 feet to the mile near Traver. The only notable break in the surface of this portion of the valley plain is made by Wahtoke Creek, which, in its southwesterly course from the foothills of the Sierra Nevada, passes to the east and south of Campbells Mountain and discharges into Kings River at the Narrows. It flows in a wide, deep gorge from foothill base to the river.

Southward from Wahtoke Creek are several minor creek channels, which carry water only in very wet seasons and sink or spread before reaching Cross Creek.

After the purchase of the 76 Canal system, in 1890, more branch canals were necessary. These were constructed, under the direction and supervision of the district engineer, by private parties, from whom they were then bought, payment being made with irrigation-district bonds. About 150 miles of branch ditches were thus constructed, at a total cost in bonds of $133,000. The entire district is now covered with branch canals, which are rarely more than 2 to 3 miles apart.

The area of land to whose surface water is now actually applied is estimated by the district officers at 40,000 acres. The distribution of

A. FURROW IRRIGATION FOR CITRUS FRUITS.

B. CHECK WEIR IN ALTA IRRIGATION DISTRICT, IN LATERAL ABOUT TWO MILES WEST OF TRAVER

water is in charge of a canal superintendent and seven assistants, called "ditch tenders."

The soil of this region is for the most part a sandy loam, with coarse, clayey sands near the eastern border of the district, and finer, lighter sands toward the west. Much alkali is in the soil to the west and southwest of Traver. Hardpan subsoils are common at 2 to 5 feet below the surface. Ground water before 1883 was at 20 to 60 feet. It was nearest the surface in the southern and western portions of this district. Irrigation is causing the water table to rise, particularly near Traver.

Water is usually available for irrigation from February until the end of July. Where used on a small scale, land is occasionally prepared for it by subdivision into small rectangular checks. This was the preferred system when water was first introduced into the vicinity of Traver. Now the contour-check method of irrigation is finding more favor. The reason for this preference seems to be due, not only to reduced first cost, but also to the fact that it requires less cutting down of surface soils than the level-check method of irrigation. The uncovered subsoils are often found to be relatively barren. Orchards, vineyards, and summer crops are quite generally being irrigated by the furrow method. Grain land, if wet at all, is irrigated by spreading water over the surface from small ditches or furrows, usually before sowing.

Morrow Ditch.—This was one of several small private ditches south of the main channel of the river which were in use for the irrigation of small tracts of land in Centerville Bottoms. It was constructed about 1865.

Dennis & Jordan ditch.—This is another private ditch, now having the appearance of a natural arm of the river. Its course is southwesterly from Patterson Slough, from which it takes water about 1½ miles below the regulator of the 76 Canal.

Kincaid Ditch.—This name is applied to an eastern arm of Patterson Slough, the head of which is about one-half mile below the head of the Dennis & Jordan Ditch. It supplies water to the Dennis Ditch and to Finks Branch.

Glenn and Barton ditches.—These are two other small private ditches, which seem to have been in use about 1879 on lands of Centerville Bottoms, but which have probably been abandoned.

Emigrant Canal.—This canal may be classed as almost out of service. It was the uppermost of the north-side Kings River canals of the lower group. It took water from the north side of Cole Slough about 2 miles below the head of that arm of Kings River. Its course was southwesterly, nearly parallel with Cole Slough, for about 3 miles, thence northwesterly to and beyond Wildflower. The canal was constructed by an organization of farmers who wanted water for their lands, and was to be managed for mutual benefit. They formed a cor-

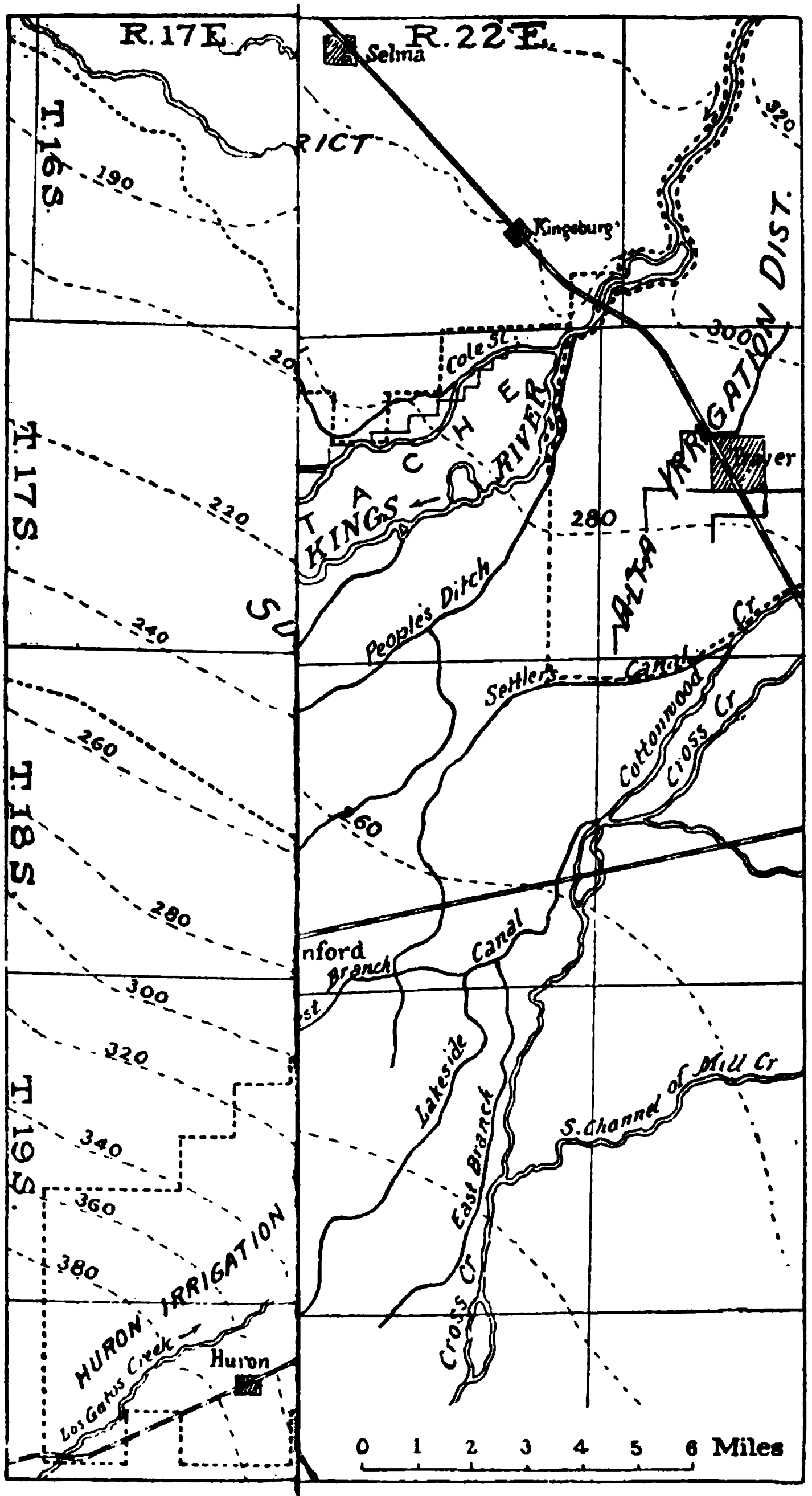
poration late in 1875, with a capital stock of $20,000, in shares of $1,000 each. All expenses of construction, maintenance, and management were met by assessing stockholders. Each stockholder was entitled to the use of canal water in proportion to amount of stock owned. He was allowed to sell or rent his water at pleasure. Each consumer of water was required to build his own delivery gate, subject to the approval of the directors. The distribution of water was in charge of a canal superintendent, which office was annually let to the lowest bidder. The canal had a bed width of about 16 feet, and delivered its water to a number of branches, which covered about 7,000 acres. The canal company became involved in litigation and failed to maintain control of its head works, so that finally it received water only during high stages of the river, and generally for such short periods of time that those dependent upon it soon found it to their advantage to secure additional water from the Centerville & Kingsburg or the Fowler Switch canals.

Liberty Canal.—This is a canal which was constructed about 1882 from the north side of Murphy Slough, its head being about 5 miles above Riverdale. After experiencing much trouble in obtaining a satisfactory supply of water from Murphy Slough, which is the extension of Cole Slough, the original head of the canal was abandoned several years ago, and it was extended easterly about 7 miles to a connection with a high-water escape way from Cole Slough known as the Sutherland Canal. The inflow into the canal is controlled by a regulator placed in the Sutherland Canal about one-eighth mile from Cole Slough. The canal is about 15 miles long, has a westerly course for 7 miles and thence a northwesterly course, is about 20 feet wide, and its branches cover about 5,000 acres to the north of Riverdale.

Millrace Canal.—Where Murphy Slough leaves the grant known as the Rancho Laguna de Tache, about 1½ miles above Riverdale, two gates or flashboard weirs have been built across the two channels of the slough. These force its water through a short canal into another natural channel, known as the Old North Channel, from which it is reclaimed half a mile below and is carried westward and thence northward in the Millrace Canal. This canal is used for the irrigation of lands near Riverdale and westward thereof. It is essentially a high-water canal. The canal proper is about 6 miles long. It has a bed width of about 14 feet.

Reeds Ditch.—One of the old ditches on Kings River is the Reeds Ditch, whose head is on the north side of Murphy Slough, about 4 miles below Riverdale. It is a small private ditch, having a course a little north of west. Its bed width is about 5 feet; its length about 4 miles. It irrigates a few acres of land near Elkhorn.

Laguna de Tache Canal (Grant Canal).—The "River Ranch," which includes the Rancho Laguna de Tache, has an area of abont 68,000 acres, embracing within its boundaries nearly all of the delta lands


R. 17 E.
R. 22 E.
Selma
Kingsburg
T. 16 S.
T. 17 S.
T. 18 S.
T. 19 S.
190
200
220
240
260
280
300
320
340
360
380
Cole St.
KINGS RIVER
People's Ditch
Settlers Canal
Cottonwood Cr.
Cross Cr.
Lakeside
East Branch
S. Channel of Mill Cr.
Canal
Branch
HURON IRRIGATION
Los Gatos Creek
Huron
0 1 2 3 4 5 6 Miles

of Kings River northward from the main stream. A main canal has been constructed for the irrigation of the greater part of this rancho, and this is known either as the Laguna de Tache Canal or the Grant Canal. A large portion of this rancho is annually submerged during the high stages of Kings River. The area subject to such flooding has, however, been considerably reduced by the construction of a north-side river levee along a portion of the ranch frontage. There are a number of north-side delta channels which break out from the main stream within this rancho, most of which have westerly courses toward the valley trough. The history of these, as related by local residents, is not without interest. The present head of Cole Slough is a water way made by the freshets of 1861–62. It was enlarged and deepened by subsequent high waters. Cole Slough is the principal north-side delta channel. Its waters are carried westward by the several branches of Murphy Slough, and finally reach the upper portion of Fresno Swamp, through which they are carried in a network of channels, as frequently found in tule swamps, to Fresno Slough and San Joaquin River, many miles northwestward.

Before 1862 Cole Slough received water from the river through a channel known as the Arroyo de Hotausas, the head of which was about a quarter of a mile below the present head of the slough. This channel was about 3 miles long.

Until 1869 Cole Slough occupied a channel which at a point about 3 miles in a direct line above Kingston was less than a quarter of a mile from Kings River, but in that year Mr. St. John, one of the owners of the rancho, made a small ditch westward from the north slough bank about 6 miles below its head. This ditch was enlarged by the next high water; it lost the appearance of a ditch, and is now called St. Johns Channel or New Cole Slough. It reunites 3 miles below its head with the original slough channel at a point also known as the head of Murphy Slough.

A small ditch, constructed in 1868 by a settler known as Dutch John, connecting Kings River with Cole Slough at the point where the two channels were nearest together, had meanwhile also been converted into a capacious water course and has since been known as the Dutch John Cut. In the same winter, 1868–69, the river broke through the barrier separating it from Murphy Slough at a point about 3 miles (by river) below the Dutch John Cut and formed Reynolds Slough, which is about one-half mile long.

The Grant Canal was constructed in 1873. Water was diverted for it from Murphy Slough, near Reynolds Slough, which latter was permanently closed by means of a dam. Two years later, by permission of the owners of the Grant, a new connection between Cole Slough, half a mile above the head of Grant Canal, and Murphy Slough, nearly the same distance below the canal, was made by settlers who were desirous of increasing the flow of water in the channels

reaching the vicinity of Elkhorn. Its projectors subsequently filed a claim to water and incorporated under the name of the Vanderbilt Canal Company. Settlers in the vicinity of Riverdale and Elkhorn claim that the original cut was entirely artificial, while owners of the Grant Canal claim that the cut is merely the result of cleaning out the head of a natural water course. After the Vanderbilt Cut had become one of the channels for Cole Slough water, the Grant Canal was extended upstream across Murphy Slough to the Vanderbilt Cut, from which it has ever since taken its water. The turning of the flow of Cole Slough into the Vanderbilt Cut is accomplished by means of a dam of earth across the old south channel. From the cut water is turned into the head of the canal by means of a second earth dam, and, flowing in the canal, it crosses Murphy Slough between two dams, of which the lower or westerly one is an overfall dam of brush work, serving as an escape

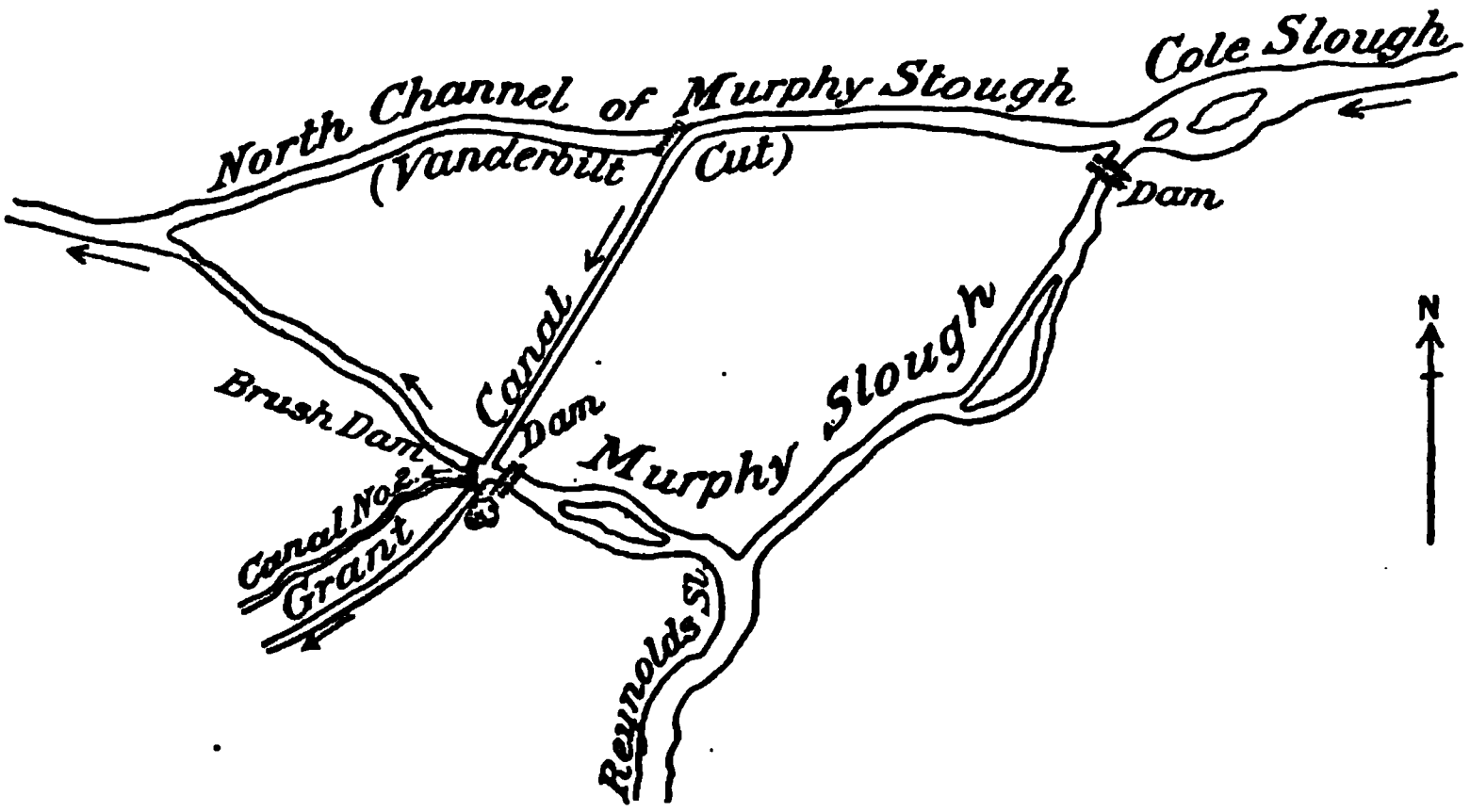


FIG. 17.—Head of Grant Canal.

way for surplus waters and feeding the lower sections of Murphy Slough.

The Laguna de Tache Canal has a westerly course along the northern bank of the main channel of Kings River, from which it is generally less than one-half mile distant. At 5½ miles below its head it crosses a water course known as the James Canal, on an earthen dam, and its direction becomes southerly. It reaches the river bank within a mile and closely follows it southerly for about a mile farther on its course, crossing and closing the head of another delta channel of Kings River known as Old North Fork.

The upper section of the main canal for a distance of about 4 miles from its head has a bed width of about 30 feet and carries water 2 to 2½ feet deep. The distributaries from the main canal are for the most part natural channels, many of which have long ago ceased to serve as delta channels and are mere swales on the tops of low ridges. The James Canal is a channel of more recent formation, which has been

ntilized as a distributing ditch. By permission of the owners of the Grant a gate for the control of its flow was put into this channel in 1880. It was washed out by the next freshets and was replaced in 1881, but was again destroyed. Thereupon the owners of the Grant permanently closed this channel with the embankment of earth on which the canal is carried across.

The head of Old North Fork, which is another distributary of canal water, was closed as early as 1865 by Messrs. Sutherland and Mann. One of the most important of the lower-river north-side delta channels is the Zalda Canal, which, throughout its lower sections, is generally known as the North Fork of Kings River. It is claimed that the head of this channel is the enlargement by flood waters of a ditch constructed in 1872 by settlers living to the west of the Grant. This channel was reported closed for a time by a dam at the river about 1885. It was at that time proposed to ntilize this channel as one of the distributaries of water from the Grant Canal. The course of North Fork is westward in a very direct line toward Summit Lake, but before the lake is reached its main channel swerves northward into Fresno Swamp. The portion of the Kings River delta between the main river on the south and the Zalda Canal on the north marks the very flat summit between Tulare Lake and Fresno Swamp. In the trough of the valley near and to the south of Summit Lake the general elevation of the ground's surface on this summit, the lowest point on the border of Tulare Lake, is about 211 feet above mean sea level. During the last high stage of the lake, in 1868, the depth of water over the general surface of the country at this point was about 6 feet.

The lands of the Rancho Laguna de Tache have always been so well watered that the irrigation works which have been constructed may be regarded as serving primarily to establish a convenient control of the water rather than as works intended to increase the supply. To prevent excessive natural inundation it has been found necessary to erect embankments along the river, also to construct numerous drain ditches from low tracts into natural channels to facilitate drainage. The main irrigation canal supplies water to a large number of distributaries, frequently natural channels, and these in turn to small irrigating ditches, usually 200 to 450 yards apart. As the entire irrigation system lies within the limits of the rancho there has been less study of methods of controlling and distributing water than would have been the case if a large number of consumers had to be supplied, and water measurement has been entirely out of the question.

The Rancho Laguna de Tache has within the last few years become the property of the same parties who control the Fresno Canal. The future of both properties was kept in mind when the owners of the Grant sold Kings River water to the Sunset irrigation district, to be diverted by way of Cole Slough into the enlarged Grant Canal, thence across the Zalda Canal (North Fork) to a proposed reservoir near Summit Lake.

According to the terms of this agreement the district is given a right of way and a reservoir site, and water is sold to it to the extent of 3,500 second-feet, subject to the prior rights of the owners of the rancho and of the Fresno Canal to the extent of 3,000 second-feet, and subject also to the proviso that, for use on the ranch, 500 second-feet may be taken out of the main canal of the district. The price paid by the irrigation district was $250,000 in district bonds, and the aggregate amount of land in reservoir sites and right of way for the canal was not to exceed 2,200 acres.

Crescent Canal.—This canal was constructed in 1885 and 1886, and came into use in 1887 for the irrigation of lands on the western edge of the extreme southern portion of Fresno Swamp. The head of the canal is on the south side of North Fork, about a mile to the north of Summit Lake. The canal, which is about 8 miles long, has a westerly course for about 1½ miles, thence northwesterly, following a grade line with a fall of 6 inches to the mile. It was originally made 50 feet wide near its head; it was 25 feet wide several miles below, and 50 feet wide in its lower sections. The narrow section was cut to the full width in 1892. It was planned to carry water 3 feet deep. A regulator is maintained in the head of the canal. This is a simple structure. Twelve light gates of 1-inch boards close the 4-foot openings between vertical posts which rise from a plank floor. The total width of the regulator between side walls is 50 feet. Its height is about 6 feet. It is weighted on top with a filling of earth. The canal supplies water to several thousand acres of land, most of which lies within the limit of overflow.

The canal is owned by an incorporated company, whose capital stock was fixed at $75,000, in 150 shares. The cost of the canal works has been about $5,000. The canal was constructed for the supply of water to lands owned by its stockholders and not for the sale of water. Each irrigator is required to own one share of stock for each quarter section of land (160 acres) which he wishes to irrigate. All distributing ditches are constructed by the irrigators, who take water from the main canal at the most convenient points.

Peoples Ditch.—This is a canal of the lower group whose head is on the south side of Kings River, about one-half mile above the head of Cole Slough. Kings River at this point flows in a broad, sandy bed to which there is a steep descent of about 15 feet from the level of the main valley plain on the south. The canal follows the margin of this plain for some distance southwesterly as it recedes from the river, and is gradually brought out upon the surface of the plain about 3 miles below its head. At about 4 miles below its head the distribution of its water to its branches commences. The diversion of water from the river is effected at low stages by means of a dam of brush and sand, which is annually repaired or renewed at considerable expense. Until within the last few years the inflow into the canal was controlled by

A. BRUSH DAM AT TIME OF HIGH WATER, PEOPLES DITCH.

B. REGULATOR IN PEOPLES DITCH, AS SEEN FROM ABOVE

two regulators, one of which was within a quarter of a mile of the river bank, the other about 2 miles below. These were 24 feet in width and were of the ordinary culvert type with vertically sliding gates.

There is a new regulating gate now in service within several hundred yards of the head of the canal. This is a massive, well-built structure, 38 feet wide between side walls, which supports an earth fill about 2 feet thick, serving as a roadway over the canal. The space between side walls is subdivided by 10-by-10-inch posts into ten bays or openings, each of which is closed by means of a vertically sliding gate. Power is applied to the gate stems by means of a lever, the end of which engages between the teeth of a rack.

The canal has a fall of only about one-half foot in the first 2 miles of its course. The effective fall is increased somewhat by keeping the brush dam at a good height. The canal as originally constructed was 24 feet wide on the bottom, and was intended to carry 4 feet of water.

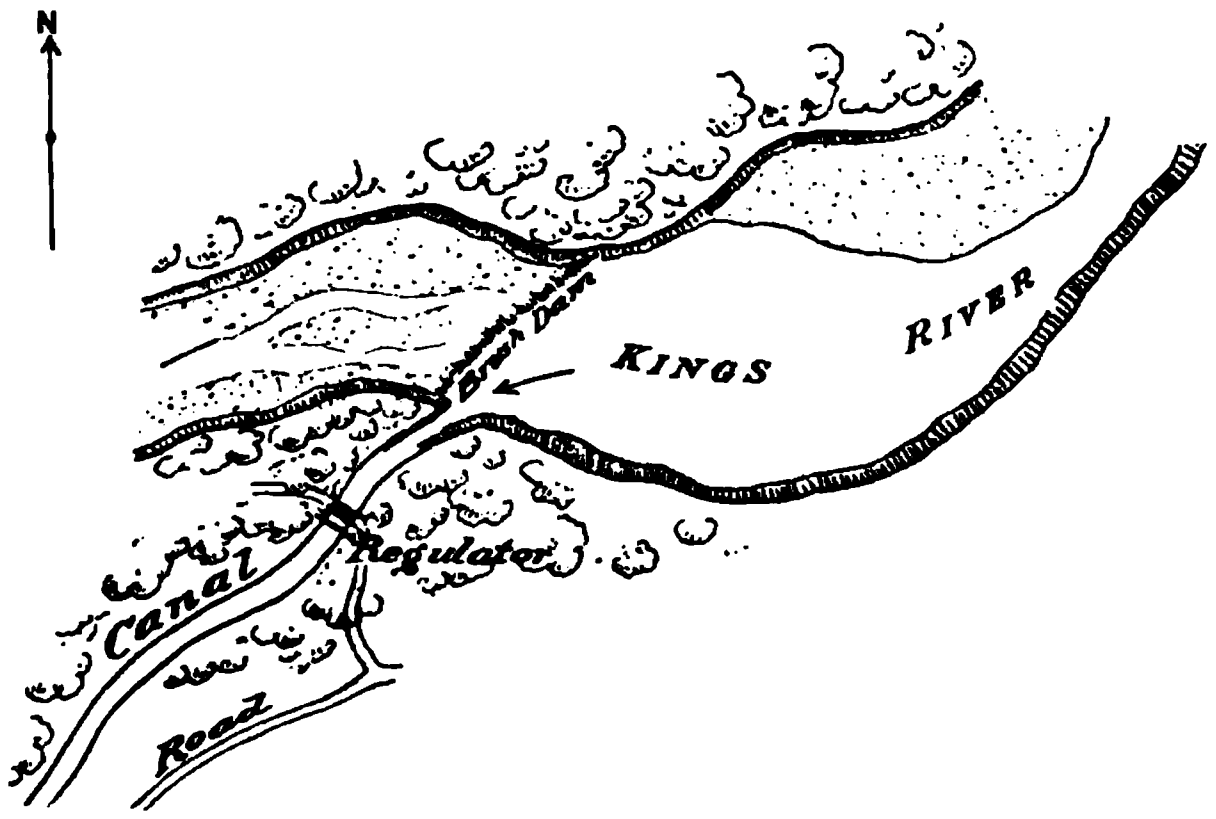


FIG. 18.—Head of Peoples Canal, on Kings River.

Its estimated capacity was about 220 second-feet. Below the second regulating gate the width of the canal increases to 30 feet, and the depth of water to be carried is only 3 feet. These dimensions are maintained for about 4 miles, still in a southwesterly direction and extending well into the northeastern extremity of that portion of the Kings River delta usually referred to as the Mussel Slough country. The canal has three principal branches: West Fork, which terminates near Grangeville; Middle Fork, which passes just to the westward of Hanford; and East Fork, which passes through the southern portion of Hanford and extends to points 4 miles farther south. The aggregate length of the main canal and its principal branches is about 37 miles. This canal was constructed by the Peoples Ditch Company in 1873 and the following years. The first notice of a claim to water was posted late in 1872. The company, formed by settlers who wanted water for their own lands, was finally incorporated in 1873. Its capital stock, originally fixed at $10,000, was soon increased to $35,000, and

later to $100,000. The first cost of the canal was about $50,000 to $60,000. The total cost of canal construction and annual expense account had reached $120,000 in 1881. About $4,000 to $6,000 are annually expended on the dam. The total annual expenditure for management, maintenance, and repairs is about $10,000.

Of the 100 shares into which the company's capital stock is divided about one-third have reverted to the corporation. The remaining shares are in the hands of irrigators, to whom water is delivered in amounts proportional to their holdings of stock. The stockholders are permitted to sell the water to which they are entitled and to ask for its delivery through any of the canal branches. Its use is not restricted to any particular tract of land. The delivery of water to irrigators is usually through gates 1 to 4 feet wide. It is discharged under pressure, the endeavor being to make amounts delivered proportional to stock which it represents, without any attempt at actual measurement. A canal superintendent, with necessary assistants, has charge of the delivery of water. Its equitable distribution depends largely on the judgment of the canal superintendent.

During the years 1883 and 1884 the experiment was tried of selling water to stockholders at $200 per share of stock per year; to those not holding stock an equivalent amount at $300 per year; but it did not prove satisfactory. All stockholders are assessed to meet the annual expenses. The area of land actually irrigated or benefited by the water of this canal is about 25,000 acres.

Mussel Slough Ditch.—This canal, which is now out of service, took its name from one of the delta channels of Kings River which has been utilized for the distribution of water. The canal, unlike the other canals of the Kings River delta, was constructed for speculative purposes. It was proposed to turn a large volume of water from the river into the slough and to derive a revenue from its sale to irrigators. The head of the canal was on the south side of Kings River, about 7 miles below the head of the Peoples Ditch. A narrow cut, the original bed width of which was about 10 feet, was made from that point southerly into and thence southwesterly along the upper portion of the channel of Mussel Slough. The bottom of this cut throughout a little more than a mile from its head was made level, being at an elevation a little below that of the river bed at the head of the canal. The upper portion of this cut, near the river, is over 14 feet in depth. As the canal leaves the river it grows wider, and at about 3 miles from its head the natural channel of Mussel Slough afforded ample capacity for its waters.

Mussel Slough and its principal branches, Sand Slough and Lone Oak Slough, have a general southwesterly course through the delta lands, passing to the west of Handford and extending to the high water line of Tulare Lake.

To what extent the canal has been in use in the last few years is not

known. It is now out of service, and was not in use for three years preceding 1886. Its head was closed with an embankment of earth in 1884, because at that time the river threatened to destroy the canal head gate and cause inundation of the upper and central portions of the delta.

The canal head gate or regulator was placed in the deepest portion of the cut, near the bank of the river. It was made 24 feet wide, the space between its walls being divided into a number of openings by vertical posts, between which gates slid vertically. The structure had the usual upper platform loaded with earth, making a roadway 20 feet wide. Its floor length was 40 feet. Sheet piling 8 feet deep was used on the upper floor line and for 12 feet under each wing; sheet piling was also driven 6 feet deep across the canal, on the middle line of the floor and at its lower edge.

Throughout the length of the natural channels utilized for the water of the Mussel Slough Ditch, check weirs or gates were constructed with which to hold the water surface at or above the surface of the ground. Irrigation was to be accomplished by subirrigation on a large scale. The charge for water ranged from 31¼ to 62½ cents per acre per year. There was little or no restriction as to the amount of water to be used by individual takers of water, and the principal duty of the canal superintendent seems to have been to prevent those from taking water who had no intention of paying for it.

The total cost of the canal works connected therewith was about $50,000 to $60,000.

This canal was constructed in 1875. Its promoters formed a corporation with a capital stock fixed at $500,000, divided into 10,000 shares, all of which remained in the hands of a few persons. The canal capacity was about 200 to 300 second-feet.

Last Chance Ditch.—One of the most important of the Kings River delta canals is the Last Chance Ditch, whose head is on the south side of the river about 2½ miles by river above Kingston. The course of the canal and its branches is southerly. It commands a district 3 to 4 miles wide, extending from near the river southerly to near the high-water line of Tulare Lake. Grangeville lies at the eastern border of this district and Armona well within it. Lands along its eastern border are commanded jointly by this canal and the Peoples Ditch. A natural cut through the south bank of the river, known as Leinberger Slough, has been utilized for the head of the canal. This slough is really one of the lower delta channels of the river. The canal is cut from its south bank about 150 feet from the river. The canal regulator is about 800 feet below its head. The water entering the head of the slough is divided, a portion flowing down the natural channel, the rest entering the head of the Last Chance Ditch. The canal has a bed width of 25 feet, and was designed for a 4-foot depth of water. Its course is a little west of south for 7 miles to a point half a mile west of

Grangeville, where it is divided into two principal branches. One of these has a southwesterly course and at the end of 3 miles drops its water into a natural channel which has a southerly course and connects with Mussel Slough. The other branch within a mile is again divided, forming a middle and an eastern branch, both of which extend far toward the south. These main branches were all made 16 feet wide on the bottom and were planned to carry water 2½ feet deep. The gradient of the canal is about 1 foot to the mile.

The original canal regulator, which was in service from 1874 to 1880, was made 18 feet wide between side walls and is reported to have cost $5,600. It was replaced by a second one, 20 feet wide, at a cost of $3,000. The removal of sand from the canals, which had been swept in by high waters during the period when there was no gate at the head of the canal, is said to have cost $3,000. The regulator is of the

FIG. 19.—Head of Last Chance Ditch, on Kings River.

ordinary box type. From a floor 30 feet wide and 36 feet long (in the direction of the canal) side walls rise to a height of 14 feet. Between them are posts which support a platform or bridge that affords convenient access to the gates. The gateposts divide the space between side walls into six openings, each of which is closed with planking permanently from the top down to about 5 feet from the floor. The remaining open space is controlled by sliding gates having a long stem or standard to which power is applied by means of a lever engaging in the teeth of a rack. The gateposts are braced from below. Long wings extend diagonally into the canal banks above and below the gate. The upper ones are 14 feet high; the lower ones about 4 feet. Tongued and grooved 4-inch sheet piling was driven 10 feet deep along the upper edge of the floor and under the upper wings. Along both sides of the floor, across the canal at its lower end and well out under

A LAST CHANCE CANAL REGULATOR AS SEEN FROM UPPER SIDE

B LAST CHANCE CANAL REGULATOR, AS SEEN FROM BELOW

the lower wings, 3-inch tongued and grooved sheet piling was driven 8 feet deep. Piles were driven to a depth of 12 feet under the braces to gateposts. Floor sills, piles, and main posts were 8 by 8 inches; side wall posts, 4 by 8 inches. The floor is of 3-inch planking, covered by 1-inch boards. Side walls are of 2-inch material, also covered with 1-inch boards. Back filling was selected sand. The bed of the canal below the gate was protected by a layer of brush, pinned down with stakes 6 to 8 feet long.

The Last Chance Ditch was constructed in 1873 and 1874 by a company known as the Last Chance Water Ditch Company, which was organized and incorporated by the farmers to whose lands it was to supply water. The original 30 shares into which a capital stock of $30,000 was divided were a few years later increased to 60 shares, and the capital stock was also doubled. Only about two-thirds of these shares are in the hands of stockholders. Until 1886 all operating and repair expenses, about $4,000 per year, were assessed upon the stockholders, and water was delivered to these without charge in proportion to amount of stock owned or controlled. Since that time water has been charged for at rates fixed annually, generally $1.50 per acre, in order to make actual users of water bear an increased portion of the canal expenses.

There has been no system of water measurement introduced. Water is delivered to irrigators through a great variety of gates; generally, however, through openings under pressure. A canal superintendent and an assistant have charge of its distribution. During the high-water period an attendant is kept constantly at the head gate. The canal ordinarily flows from the beginning of February to the end of July. About 20,000 acres of land are dependent upon it for water.

Lower Kings River Canal.—This is another south-side canal in the Kings River delta. Its head is about 6 miles below Kingston. Its course is southerly, and the district it commands lies just westward of that of Last Chance Ditch and has Lemoore in its center. The canal is cut southerly from the river, and at the end of its first mile reaches Leinberger Slough, into which its water is dropped. It is reclaimed from this slough less than half a mile below that point, and thence has a southerly course to within about 3 miles of Lemoore. Two principal branches, each about 16 feet wide on the bottom, extend toward the south from this point. Near the river the main canal crosses high-water sloughs fed by the over-bank flow from Kings River. These natural channels have been closed by dams on the lower or west side of the canal. Their water, together with other water escaping from Kings River above the head of this canal, is received by the canal and carried to Leinberger Slough. At the point where the canal leaves this slough a waste way 260 feet long is maintained, through which surplus waters are discharged. This is a very light timber structure, which is reported to have rendered good service. Some years ago it was proposed to

supplement it with a second waste gate, 200 feet long, nearer the head of the canal. The main canal regulator or head gate has been set close to the river bank. A secondary regulating gate is just below the Leinberger Slough waste gate. Each gate is about 40 feet wide between side walls. The head gate is arranged similarly to that described for the Last Chance Ditch. The main canal is about 40 feet wide. It was built on a very light grade. The bottom of the canal, commencing at the same elevation as the river bottom, was reported level throughout the first 5 miles of its course. The effective gradient slope of water surface when full is reported at 4 inches to the mile, with a 2½-foot depth at the forks of the canal. Work on this canal commenced in 1870. Twenty-seven persons joined in an agreement under which the canal was to be constructed, and which provided that each person was to bear a proportional part of "all expenses above" his "further boundary." It was at first made 18 feet wide on the bottom near its head, and 10 feet wide at 5 miles below its head. It was enlarged in 1873. The first head gate was constructed in 1872 and is reported to have had a width of 18 feet. It was washed out the following winter and was at once replaced by another, which was in use till 1876. After this second regulating gate was swept away the canal was operated without an upper gate until 1879, when the third regulator, 40 feet wide, was built, at a cost of about $3,000.

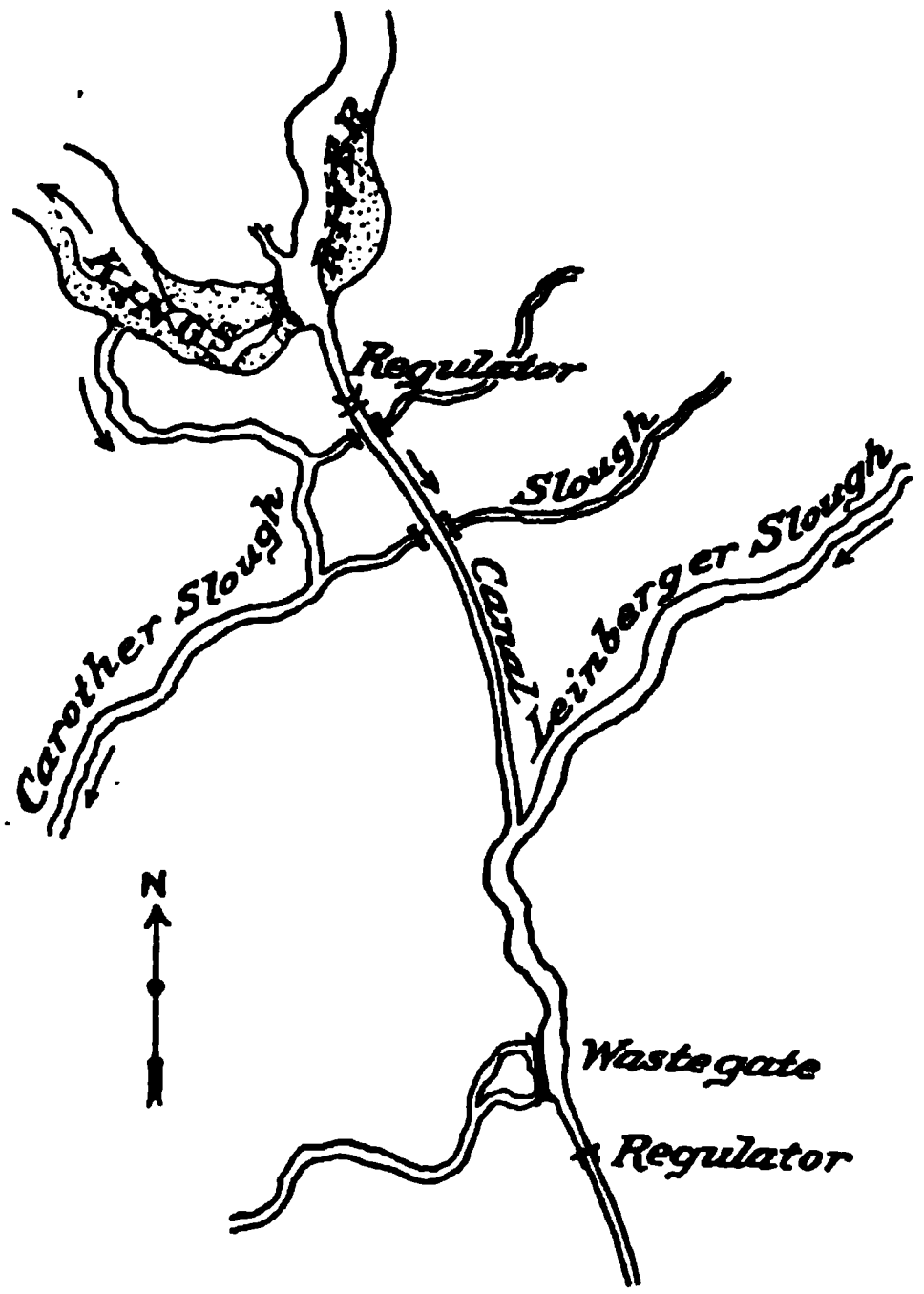


FIG. 20.—Upper section of Lower Kings River Canal.

The canal was built and is owned by those to whom it supplies water. Its owners, who had organized as a company, formed a corporation in 1873, with a capital stock fixed at $30,000, in 100 shares.

The water in the canal is supposed to be represented by those shares of stock which have been issued, which is a little more than one-half of the full number of shares of capital stock. It is sold by directors of the company, but only to the extent of the shares which have been issued. Each of these represents a proportional part of the flow of the canal until such part exceeds 144 miner's inches. Water in excess of

this amount is at the further disposal of the company. Stockholders are preferred purchasers of water to the extent of the shares owned by each, and provided the application for water is made preceding a fixed date. Each share of stock is supposed to represent sufficient water for 320 acres. The annual cost of canal management and repairs is about $1,500 to $2,000. The first cost of the canal was about $30,000. For a number of years after organization all expenses were assessed upon the stockholders, but, this proving unsatisfactory, the plan of selling water was introduced, with good result. The extent of irrigation from this canal may be noted at about 10,000 acres.

Rhoads Canal.—Lands to the west of Lemoore to the extent of 3,000 or 4,000 acres are dependent in large measure upon the flow of the Rhoads Canal for irrigation water. This canal in its upper section has the appearance of a natural high-water channel. From a point on the south side of Kings River about 1½ miles below the head of the Lower Kings River Canal, this channel has a southwesterly course for 2 miles to Carother Slough. It is known as Wrights Cut, and is claimed to be the enlargement of a small ditch constructed many years ago. The Rhoads Canal is carried southward from the termination of this cut at Carother Slough about 7 miles. It has a bottom width of about 16 feet and carries water about 2 feet deep. Water is taken from Carother Slough so long as the slough has a sufficient flow; thereafter a little work is done at the head of Wrights Cut to turn more water from the river into the canal.

The canal is reported to have been in use since 1868. It replaced a small ditch, about 5 feet wide, which had been in use some years before. The canal belongs to a number of farmers, who by mutual agreement apportion its water and expense of maintenance among themselves. There is no regulator at the head of the canal. Water is taken by each irrigator as he may require it. No water is sold, and all contributions toward expenses of maintenance are voluntary, as there are no means of enforcing their payment.

There are times when much more water flows in Wrights Cut than can be carried by the lower sections of the canal. The surplus reaches Green Slough through Carother Slough, thence Esrey Slough and other natural channels, and is finally reclaimed for the irrigation of lands about 4 miles southwest of Lemoore.

Jacobs Canal.—This is a private high-water canal, constructed about ten years ago for the benefit of lands along the northern margin of Tulare Lake, below the lake's high-water line. Its head is about 6 miles southwest of Lemoore.

SUNSET IRRIGATION DISTRICT.

As the construction of the works for this district has not commenced, a brief reference to the district and its proposed source of supply will suffice. The district covers the lowest portion of the west side plain of San Joaquin Valley, extending northward from the southern limit

of Tulare Lake about 70 miles, to within 3 miles of Las Juntas, the point where Fresno Slough unites with San Joaquin River. Its width ranges from 1 to 12 miles and its area is about 363,500 acres. The district organization was completed in March, 1891. After estimates of the cost of works necessary for its irrigation were made, a bond issue of $2,000,000 was voted. Of this bond issue $250,000 were paid for water rights, reservoir site, and rights of way.

The plan of irrigation involves the construction of a large reservoir in the vicinity of Summit Lake, which is to be formed by the construction of two embankments of earth, each crossing the valley trough from east to west. Water is to be supplied to this reservoir from Kings River by way of Cole Slough, the enlarged Grant Canal (which is to be used in common with the owners of the Grant), and a canal extension to be carried from near the lower end of the Grant Canal in a direction a little south of west across the North Fork of Kings River to the reservoir site. From the reservoir there is to be a canal northward and a second one southward, both supplied with water by gravity flow from the reservoir. In addition to these two low-level canals there are to be eight other canals, four northward and four southward, each 11 feet higher than the one next below, and each to be supplied with water by means of centrifugal pumps arranged in four pumping stations.

The specifications drawn for this work do not indicate how the seventeen pumps that are prescribed are to be apportioned to the several pumping stations. The pumps are each to have a capacity of 100 second-feet raised 11 feet. The district canals are to be of sufficient size and length to carry water to all parts of the district. The requirements concerning canal dimensions are not made specific; they are to be suitable to the service required, which, it appears, remains to be determined as work progresses. The aggregate length of the proposed district canals is estimated at 500 miles. The contract for the construction of the canal system complete, including the necessary pumps, engines, and boilers, has been let for $1,500,000, and the same person who has taken this contract is also the purchaser of the bonds of the district. It is distinctly expressed in the contract that in case the bonds are not taken the contract may, at the option of the district directors, be set aside. The contract was made several years ago, and was conditioned upon a decision by the Supreme Court of the United States sustaining the irrigation-district law. This having been rendered, it is understood that the contractor has now declared his readiness to proceed with actual construction work.

THE FRESNO PLAINS.

DESCRIPTION.

The main canals which divert water from the north side of Kings River at or near the upper end of Centerville Bottoms and command that portion of the San Joaquin Valley plain in the vicinity of Fresno, Selma, and Kingsburg may be designated the Fresno group of canals. These canals are the Kings River & Fresno Canal, the Fresno Canal, the Fowler Switch Canal, and the Centerville & Kingsburg Canal, all of which have already been described. Their branches extend throughout an area of nearly 400 square miles, which before canal construction was a treeless, sandy plain. It was almost devoid of natural water courses. The few creeks whose periodical flow reached the eastern border of the plain to the north of Kings River were soon lost, and there was no sign of a channel beyond their "sinks." The natural water courses in the eastern portion of the district under consideration, in their order northward from Kings River, were Burns Slough, Kip (Lone Tree) Slough, Mud Slough, Mud Creek, Fancher (Fanshaw) Creek, Red Bank Creek, Frolic Creek, and Big Creek. Of these, the first three lie to the south of the point of the mountain which with gentle slope extends westward on the north side of Kings River to a point 2 miles north of Centerville. Burns Slough is a tributary of Kip Slough. The sink of Fancher Creek, now a fine vineyard, is about 4 miles east of Fresno. The waters of Red Bank and Frolic creeks, after uniting in one channel, spread and disappear 6 miles east of Fresno, near where Temperance Colony has been established. The sink of Big Creek is several miles to the northwest of Fresno.

Some of the channels of these creeks have been made part of the canal system. Portions of Burns Slough and Big Creek are utilized for water of the Kings River & Fresno Canal. Other portions of Burns Slough, Kip Slough, Mud Slough, Mud Creek, and Fancher Creek are now the main channel of the Fresno Canal. Lone Tree Creek is an important distributary of the water of the Fresno Canal. By the utilization of these natural water courses the canals are made the recipients of the drainage water from the foothills, and are, at time of considerable rainfall, taxed beyond their capacity, and have repeatedly in the last few years inundated parts of Fresno and vicinity. A proper drainage system in this locality is now recognized as a necessity, and no doubt will be planned and executed in the near future. The general slope of the Fresno irrigated region is from northeast to southwest, at the rate of 5 to about 7 feet to the mile. The surface of the country for the most part is very smooth, though broad belts of hog-wallow or knolly ground are occasionally found. The knolls of these hog-wallow belts are generally 1 to 2 feet in height, rarely as high as 3 or 4 feet. The knolls are close together, and diameters at the

base of from 20 to 40 feet are most common. Where they occur the expense of preparing land for irrigation is increased. Except where unusually high they do not interfere seriously with ordinary farming operations when land is not irrigated. They often indicate land of inferior quality, hardpan being frequently found beneath a shallow layer of surface soil.

Near Centerville the soil of the upland is a red sandy loam, resting on a yellow clay hardpan, which is usually at 4 to 6 feet below the surface. Hardpan is not continuous; it disappears frequently at about one-half mile from the margin of the upland, where the surface soil becomes lighter and more sandy. At depths of 10 feet or more beds of cobble and gravel are found, which in proximity to the low river bottoms afford thorough underdrainage to these lands. The soil is very productive. Ground water is at 12 to 15 feet below the surface.

Westward from Centerville toward Fresno the soil of the plains is a loamy sand. This generally rests on a firm clay hardpan, which is sometimes impregnated with sand. Soil is from 1 to 3 feet deep. At the sinks of the several creeks near Fresno the soil is a deep, heavy, red loam, baking on the surface after being wet. Where a hardpan substratum is encountered at all it is at 10 to 30 feet below the surface. Westward from the immediate vicinity of the sinks of the creeks the soil is a loamy sand, several feet deep, resting on a firm clay hardpan. The soil far toward the southwest merges into the sandy soils of the alkali belt which skirts the edge of Fresno Swamp, and these in turn are succeeded by the rich peaty alluvium of the swamp lands. To the south of Fresno the sandy soil of Fresno and Central California colonies changes to the light so-called ash of Washington Colony. The hardpan dips farther below the surface toward the south, and there are points in the latter colony where it has disappeared altogether. In the southern and southeastern portion of the region commanded by this canal system sand predominates. The surface of the country is comparatively smooth, though occasionally crossed by low sand ridges. Firm hardpan, partaking of the nature of cemented sand, immediately below the surface soil is rarely found. It occurs most frequently where the surface presents the peculiar hog-wallow appearance.

The rainfall in the region commanded by the Fresno Canal system is greatest near the base of the foothills. It decreases from there toward the west. At Centerville the average fall of rain is about 16 inches, while at Fresno and Kingsburg it is 9 inches. The average fall at Firebaugh, 30 miles to the west, in the trough of the valley, is about two-thirds of that at Fresno. For the irrigated region near Fresno the mean annual fall of rain may be noted at about 9 to 10 inches. When this amount of rain falls at the proper time it is sufficient to insure fair crops of grain. Throughout a large part of the region rainfall is relied upon to produce a crop, and irrigation of grain is resorted to only when an unusually dry spring threatens the destruction of a growing crop. The products which can not be raised without irrigation are alfalfa,

grapes, fruits of all kinds, including citrus fruits, corn, melons, etc. Two of the canals irrigating lands near Fresno have a perennial flow; the others divert water only during medium and high stages of the river, generally from January to August, inclusive. The aggregate capacity of the four canals already enumerated is about 1,550 second-feet. None of them, however, flow for long periods at their maximum capacity. The demand for water is, fortunately, greatest at the time when the flow of the river is greatest, during spring and the early part of summer.

THE CANAL SYSTEM.

All of the canals of the Fresno system take water from Kings River above Centerville. Each of them is out upon the upland before passing that village. Such duplication of canal work seems unnecessary.

Each of these canals was constructed for the purpose of supplying water to some particular point or place of use; thus, the Fresno Canal to irrigate lands in the immediate vicinity of Fresno, the Kings River & Fresno Canal to irrigate a strip of land just north of the Fresno Canal, the Centerville & Kingsburg Canal to irrigate lands near Selma, and the Fowler Switch Canal to supply water to the vicinity of Fowler and lands westward from that point. By reason of such special requirement in each case, each canal received an alignment as direct as possible from the proposed source of water to the point of delivery. The main canals were therefore constructed without attempt to hold them to any uniform grade. They have alignments in the direction of the greatest fall of the country, and generally, when their grade is excessive, check weirs are used to prevent erosion. The flow of water in the Kings River & Fresno Canal and in the Centerville & Kingsburg Canal is thus regulated. The regulation in the case of the Fresno and the Fowler Switch canals is only partial. The water of the former of these canals in Fancher Creek is generally 8 to 15 feet below the surface of the ground, its elevation being uncontrolled by structures.

The Fowler Switch Canal was constructed on a very irregular grade line. Its grade, when possible, was placed at 1.92 feet to the mile, which was established as the minimum gradient. At some points, however, the grade was no less than 12 feet to the mile for short distances. The dimensions of the canal were calculated on a basis of a fall of 1.92 feet to the mile, and were not modified for heavier grades. Consequently, canal dimensions where this grade was exceeded are excessive. The canal was originally constructed without structures, either for the regulation of its flow or to facilitate diversion. Rapid erosion at once commenced where the canal bed was not in very firm material, and after a short experience a limited number of check weirs were put into it at the points where most required. The structures in this and in the other canals of the district are very light timber affairs, but generally well adapted for the purpose which they are to serve.

In view of the fact that the irrigation of this region has in the past

it and soils are kept moist by the water rising from below. Surface wetting has become unnecessary in many sections.

Where land is held in tracts of 20 to 40 acres, as in the colonies near Fresno, the subdivisions of alfalfa, vineyard, orchard, etc., are small. The individual irrigator has but a small area of soil to moisten and, because many irrigators in his neighborhood necessarily require water at the same time, he can probably command but a small flow with which to accomplish his irrigation; consequently he devotes more than ordinary care to the preparation of his land, and if the duty of water is not so high on his lands as it ought to be the good will of the irrigator is not at fault.

The subdivision of land holdings into small tracts and the greedy absorption of water at the outset by the dry soil of the Fresno plains were the prime factors which have controlled methods of irrigation. That which most frequently found favor was flooding in small checks whose surface had been made perfectly level, it being extremely desirable to quickly cover the whole surface to be wet with a thin sheet of water. Drainage appeared unnecessary, as all surplus water delivered into a check rapidly sank into the ground.

The area of these level checks generally ranges from one-quarter of an acre to 2 acres. They are nearly always made rectangular. In alfalfa fields the levees inclosing them are often made so flat and low that farming implements can pass over them. Their position is adapted to the configuration of the country, in order to make the work of leveling as small as possible. Irrigation ditches are so arranged that there is an inlet from a ditch into each check. No drains are provided. All surplus water entering a check is allowed to sink into the soil. The cost of preparing land in this way has been variously stated by the irrigators at from $15 to $50 per acre.

Water is admitted into the several checks through small gates, or occasionally through small sluice boxes, generally constructed of 1-inch redwood. Water in the irrigating ditches is controlled by means of small gates closed by loose boards moving easily in vertical grooves. Sometimes a notched board is set across the ditch, so arranged that the notch can be closed by means of a board upon either side of the notch.

The system of flooding in checks formed by contour levees, which has found much favor with Kern River irrigators, is in use only for the irrigation of large tracts of alfalfa, but where used in the vicinity of Fresno the area of the checks is kept small, rarely exceeding in any case 3 or 4 acres, whereas in the Kern River country the area of a single check frequently exceeds 10 acres. Contour levees are lower for checks of smaller area. The expense of ground preparation is greater, but irrigation is more economical, as with small checks much time and water are saved. The contour levees usually follow closely 4-to-6-inch contour lines. Soils are so porous that irrigation in each check is complete when water has been made to cover its whole area,

otherwise there is no deviation from the ordinary practice of irrigation in contour checks.

A third system of flooding is sometimes practiced, though it has not found general favor. It is that of flooding the surface with water from small ditches which are carried along the tops of ridges, or very nearly on contour lines. The water of these is made to overflow one or both banks, and as the thin sheet of water flows over the surface it is guided and to some extent controlled by attendants. Unless the ground is very knolly this system requires but little preparation, except the construction of the irrigating ditches, but the application of water is attended with much greater expense than under the preceding systems. It has been in use for trees and vines as well as for alfalfa.

The furrow method of irrigation is growing in favor. It is practiced in many ways, according to conditions of surface slope and crops to be irrigated. When water is to be supplied to the surface of grain land in large areas it is generally done by the furrow method. Distributing ditches supply water to plow furrows or to small temporary ditches which are placed so close together that water can readily permeate the surface soil, particularly that portion of it which has been loosened by the plow. The furrows may be run on or near contour lines; they may be run in the direction of the greatest slope of the ground's surface, or they may be run in parallel lines between the rows of trees, vines, corn, vegetables, etc. Sometimes this system of irrigation is practiced in level checks for trees and vines in preference to the plan of flooding the whole surface.

When grain land is to be irrigated by the furrow method the furrows are drawn 8 to 12 feet apart in the direction of the greatest slope of the ground, unless this be so great that water flowing in the furrows would cause erosion. Should this be the case they are drawn obliquely to the greatest slope. The irrigating ditches are located on the ridges, if there be any, or on grade at intervals of one-half to one-quarter mile from near the upper edge of the tract to be irrigated, and about parallel with it, to near the lower edge of the tract. The irrigation commences at the highest point of the field from the upper ditch. Water is admitted into a number of furrows, in which it flows until moisture reaches the next ditch; it is then turned into other furrows, until all the furrows between the first and second ditches have been wet. Hereupon the water is turned into the second ditch, another set of furrows is wet, and so on until irrigation is complete.

This system of wetting from furrows is practiced for grain land as well before seeding as when a growing crop is to be irrigated. In the latter case the refilling of small ditches and furrows that would otherwise interfere with harvesting operations adds somewhat to the expense of irrigating.

Under the furrow system of irrigating each attendant ordinarily controls about 1½ to 2 second-feet, and water is generally turned off at

night, owing to the difficulty of controlling it in the dark. On the sandy soil of the region covered by the Centerville & Kingsburg Canal, where this method of applying water has found more favor than elsewhere, irrigation progresses at the rate of about 2 acres per day for each second-foot of water. Each irrigation is there equivalent to an average depth of one-half foot of water over all the land irrigated. It should be stated, however, that very little wheat land is regularly irrigated on the Fresno plains at points where water must be applied to the surface soil. Irrigation is rather a last resort to save a growing crop which the farmer hoped would mature without irrigation. For the regular irrigation of grain land it is customary to rely upon one irrigation in the fall of the year before plowing. The moisture then absorbed is sufficient to supplement the scant rainfall and make a good harvest reasonably certain.

The lack of natural deep-cut drainage lines through the lands of the Fresno district has already been alluded to. Their absence has made possible the remarkable filling of the subsoils with water and the rising of the ground water to within a few feet of the surface. Whenever ground water is brought so near the surface that capillary attraction and the hygroscopic properties of soil cause water to rise sufficiently high to moisten the surface layers of soil, other methods of supplying moisture become unnecessary. Crops are irrigated if ground water is permanently held at this height, or if it is so frequently raised to this height that the soils under cultivation receive all the moisture required from below. Where water is thus brought within reach of plant roots the system of irrigation is locally often referred to as "irrigation by percolation." It becomes a system when, as in the Mussel Slough country south of Kings River, the canals at the proper season supply the requisite amount of moisture to the cultivated tracts without burdening them with an injurious surplus during the rest of the year.

By the rising of the ground-water plane near Fresno large tracts of land have been permanently moistened. Some are very thoroughly subirrigated, and in many instances injuriously so. Relief must be sought in some localities either by drainage or by proper regulation of the supply of water to the district, whereby the elevation of the water table may be controlled.

Near the Fresno Canal, about 7 miles northeast of Fresno, lands were already too moist in 1882 to permit farming operations. Drain ditches 4 feet deep were then in use in Temperance Colony to drain the surface soil. In 1885 drain ditches 4 to 6 feet deep were in use in the Eisen vineyard, 5 miles east of Fresno, to keep ground water at least 4 feet below the surface of the ground. Parts of the town of Fresno, parts of Fresno and Central colonies, and lands to the north and west of Fresno may be cited as other instances of the too close proximity of ground water to the surface.

Some reference has already been made to the time of irrigating cer-

tain kinds of crops and the amount of irrigation accomplished by a stated amount of water. Some further illustration of the time when water is required for different products, and of the quantity absorbed by soils under the various conditions of irrigation in this vicinity, may not be out of place here.

Alfalfa, except when the water table is so near the surface that soil is kept moist from below during the entire growing season of this plant, is almost invariably irrigated once for each crop of hay cut. The first irrigation is early in spring and the first hay is cut in May; the succeeding ones at intervals of about five or six weeks. The number of crops cut is generally four; the average yield per acre is 1 to 1½ tons per cutting. Irrigations subsequent to the first of the season are given either before or just after the cutting of each crop. It is said in favor of irrigation before cutting (about one week or ten days) that then the ground's surface is shaded, it does not bake so hard in drying, and the new growth of alfalfa is better able to withstand the heat of the sun than if subjected to an irrigation after the hay is cured. But, whenever alfalfa is irrigated before cutting, in checks not perfectly level, water in some parts of these stands too long about the plant, too much of the plant is submerged, and the quality of the hay is impaired.

Where the ground water is so close to the surface that it supplies sufficient moisture to alfalfa land, occasional floodings are necessary to drown gophers.

Trees and vines were, until the last few years, very copiously and very frequently irrigated in this region. Trees were generally watered three or four times during the spring and summer; vines sometimes every two to three weeks. The water during the first years of irrigation near Fresno was, almost without exception, applied to the surface, and the result was that the roots of trees and vines frequently failed to penetrate into the subsoils, entailing evils which could not easily be corrected and which were particularly apparent in the quality of the product. The lesson was not quickly learned, but there has been decided improvement. Less moisture is supplied to the surface soils and greater care is taken to keep the surface well cultivated. Capillary attraction is thus interrupted at the depth to which the plow has penetrated, less moisture is brought into direct contact with the air, evaporation is consequently reduced, and plants are enabled to get the greatest possible benefit from the moisture already in the soil. Some examples from actual experience may illustrate how water is here used.

On June 16 to 17, 1882, 5 acres of alfalfa in small checks thoroughly leveled were irrigated in eight hours, from 6 p. m. to 2 a. m., in Central California Colony. The head of water used was 0.84 second-foot. The amount of water absorbed by the soil was equivalent to a depth of 0.11 foot over the entire 5 acres.

On the 17th of June, 1882, in Central California Colony, a supply of 2.26 second-feet was divided into four parts and each admitted into an

alfalfa check having an area of 1¼ acres. The irrigation of the alfalfa commenced at 6 a. m., and at 4 p. m. the water had been made to cover the entire area of each check. Alfalfa was being irrigated before cutting. The checks were level and no water was drawn off. The total amount supplied was equivalent to a depth over all of 0.37 foot. The soil was sandy loam; hardpan was 6 feet below the surface; ground water at about 12 feet. Less water would have been required if the whole stream had been admitted in turn to each check.

On June 12, 1882, in Central California Colony, two checks of alfalfa, 290 by 130 and 290 by 200 feet, respectively, were irrigated at the same time with 1.2 second-feet. Water was applied from 9 a. m. to 8 p. m. The total amount supplied was equivalent to a depth of 0.49 foot over the whole area of the alfalfa. The soil was a sandy loam, with hardpan at 1 to 2 feet. This alfalfa was to receive five such irrigations during the season.

On the Gould Ranch, north of Fresno, one attendant in 1882 handled about 1 second-foot of water. With this amount of water orchard lands were irrigated at the rate of about 4 to 5 acres per day of twenty-four hours. The average depth of the water applied over the whole surface of the orchard was 0.40 to 0.50 foot. The orchard received two to three irrigations per season. The trees of the orchard are set about 16 feet apart in rows 24 feet apart. Water was run in small ditches along each row, and was made to stand around the body of each tree while irrigation was in progress. The surface of the ground was not leveled when the orchard was set out. The soil is a heavy, dark loam, with hardpan at an average depth of 5 to 7 feet.

About 4 miles northeast of Selma 2 to 3 acres of vines or trees could be irrigated in 1882 in one day of twelve hours with 1 second-foot of water. The soil is a sandy loam, with no hardpan under it. It bakes on the surface in drying. Ground water was then some 40 feet below the surface. The method of irrigation is that of running water in furrows between rows. Several such irrigations per season are given to trees and vines.

In the same vicinity in 1882, irrigation of grain with 2 to 3 second-feet was progressing at the rate of 3 to 4 acres per day of twenty-four hours. The method of irrigation was the furrow method. Furrows were 10 to 12 feet apart. The soil was thoroughly saturated by percolation. The amount of water absorbed was sufficient to have covered the entire surface to a depth of 1.42 feet. One irrigation at any time after harvest is sufficient to mature the grain crop of the next season. The soil is a sandy loam, which bakes after wetting, unless cultivated before drying. Hardpan is not continuous; where it does occur it is generally at 8 feet below the surface. Ground water is at 35 to 40 feet.

On June 12, 1882, in Central California Colony a small check of grape-vines, one-fourth acre, was irrigated in fifty-five minutes. The check was level and all water standing in it at the end of the fifty-five minutes

was allowed to soak into the ground. The soil was still somewhat moist at the time this irrigation commenced. The soil is a sandy loam 1 foot deep, resting on a firm hardpan, through which holes were cut when the vines were set out. The amount of water supplied was 0.8 second-foot, and the total amount was sufficient to cover the ground 0.25 foot deep. The vines appeared thrifty and in splendid bearing. Such irrigation was repeated about every three weeks until the grapes had matured.

About a mile east of Selma, where the soil is a sandy loam 10 to 25 feet deep, with ground water at 24 feet, it was said in 1882 that 2 acres of wheat land could be irrigated in one day of twenty-four hours by one attendant with 1½ to 2 second-feet of water, equivalent to a depth of water over all of about 1.74 feet.

The foregoing statements must not be accepted as an indication of the ultimate duty of water on the Fresno plains. The area irrigated per unit of water will continue to increase, at least until irrigation produces no further permanent changes in the elevation of the ground-water plane.

Without attempting to express in detail the acreage irrigated per cubic foot per second of canal capacity or actual flow of water, it may be noted that the total volume of water brought to the vicinity of Fresno during the seventeen years 1879 to 1896 would at a very low estimate have covered to an average depth of about 0.8 foot per annum the entire 260,000 acres of the region through which the canals send their branches. It would have covered the 50,000 acres to whose surface water is actually applied to an average depth of 4½ feet per annum, or to a total depth of 75 feet. Some of this water has of course been consumed in sustaining plant life, more has been evaporated, but the most of it still permeates the subsoils of the irrigated region and of the lands to the west.

WILDFLOWER.

The Wildflower country is a small portion of the east-side plain of San Joaquin Valley just south of the Kings River delta lands. Its limits may be considered coextensive with the area covered by the Emigrant Canal and its branches. Sandy soils predominate, the heaviest being near Cole Slough in the southeastern portion of this region, and the lightest along its northwestern border. The usual strip of bad lands, strongly alkaline, is found at the south, near the overflow limit from Kings River. Hardpan does not appear in a continuous layer under the soil; it is found in spots or belts of small extent, generally 4 to 8 feet below the surface, and usually but a few inches thick.

For a number of years all the water used for irrigation near Wildflower was supplied by the Emigrant Canal. As this canal became unreliable as a source of supply (due mainly to litigation concerning

ownership of its head works), water from other canals, the Fowler Switch and the Centerville & Kingsburg, was brought into the same district.

The irrigating period while the Emigrant Canal was in full service continued from March to the end of August. All the water of the canal during that period was apportioned to the distributing and irrigating ditches, and was allowed to sink from these into the subsoils. The method of irrigation was essentially that of subsurface saturation, which will be fully described in the notes on the Mussel Slough country. Alfalfa fields are sometimes subdivided into small rectangular checks of one-half acre to 2 acres each, and receive an occasional flooding. The surface of the country is very smooth, and no leveling or smoothing of the surface was necessary, as at Fresno. All water delivered into a check is allowed to sink into the soil, which readily takes it. Orchards and vineyards are irrigated, while water is available, by conducting it between the rows of trees and vines in small ditches. Summer crops are irrigated by the furrow method. Before lands were irrigated ground water was here at 10 to 16 feet below the surface; it has risen, as the result of irrigation, about 6 feet.

LIBERTY AND MILLRACE SETTLEMENTS.

The region watered by the Liberty and Millrace canals is a continuation of the Wildflower country westward, and the same notes with reference to soils apply. Water supply has usually been restricted to a few months each year, and the process of subsoil saturation has been rather slow. Irrigation is accomplished by flooding in small contour checks or by filling small ditches or furrows between rows of trees, vines, corn, or vegetables. Water is so freely absorbed by soils that no drainage is necessary.

LAGUNA DE TACHE RANCHO.

This grant, which extends southwesterly along the north side of the main channel of Kings River a distance in a direct line of about 25 miles, from near Kingsburg to Summit Lake, embraces the major portion of the north-side delta lands. Its hydrographic features have already been dwelt upon, and but little more is to be said concerning the use of water upon it for irrigation. The surface of the ground is smooth; there are no irregularities except such as have been produced by Kings River waters. Predominating soils are deep, sandy loams. Some of the depressions near present water courses, particularly in the northwestern and northern portions of the rancho, have sedimentary soil. The upper portion of the rancho, along Cole Slough, is in the alkaline belt. The surface slope from east to west is about 4 feet to the mile. Near Kings River is a fine growth of oaks. Willow thickets abound near the river in the southern portion of the rancho.

The many delta streams have always furnished an abundance of water to subsurface strata, so that depth to ground water has never been very great—4 to 16 feet, varying somewhat according to locality, and no doubt also somewhat with the seasons. The local control of fluctuations in the elevation of the water table is one of the features of the method of irrigation. The canal supply is ample from February to August. Little or no water is put upon the surface of the ground. Tracts to be irrigated have ditches generally located on the slight ridges built up by former water courses, from which water sinks into subsoils. Surplus waters are drained from the flat depressions between these ridges by a simple system of drain ditches. Crops irrigated are principally natural grasses and cereals.

MUSSEL SLOUGH COUNTRY.

Description.—All of the Kings River delta south of the main channel of the river and west of Cross Creek is commonly known as the Mussel Slough country. Many water courses, locally called sloughs, former channels of Kings River, course through this region from north to south. The heads of most of these have long been filled with deposits from the river. Others have more recently been artificially closed. A great many have been made parts of the distributing system of the irrigation works of this region.

The surface of the Mussel Slough country slopes from northeast to southwest at the average rate of about 4 feet to the mile, which is only about one-half the fall of the ground's surface in the vicinity of Fresno.

The soil of this region is all sedimentary. Most of it is sandy loam, varying somewhat in texture and color in different localities. It is sandiest toward the east and northeast; heaviest toward the west and south, where it merges into the peaty clays of the swamp-land belt. From northeast to southwest, at Grangeville, a strip of land several miles wide extends through this region, whose soil is a dark, rich loam, generally considered of the best in the delta. All soils are deep, resting upon subsurface strata of sands and soft, sandy clays.

Before the construction of the irrigation canals in the Mussel Slough country, depth to ground water was 10 to 18 feet. It was found at greatest depth in the eastern and southern portions of the delta. Irrigation very soon brought the water table close to the surface of the ground, and throughout the irrigated portion of the south-side delta it does not now sink to over 8 feet below the surface. It has an annual fluctuation, rising during the spring months when canals are full of water, and falling again in the fall of the year. In some localities this rise is so pronounced that standing water appears in the depressions, forming ponds which do not entirely disappear until the close of the irrigating season.

Canal system.—The Mussel Slough country is supplied with water

for irrigation from Kings and Kaweah rivers. The former sends water through the Peoples, Last Chance, Lower Kings River, and Rhoads canals to the northern, central, and western portions of the south-side delta, while Kaweah River supplies water to its eastern portions through the Settlers and Lakeside canals. For about six months each year, commencing with February, Kings River furnishes an abundance of water for the canals leading from it. The canals from Kaweah River are not so copiously supplied with water, because that river is subject to greater irregularities of flow than Kings River. Their period of flow is not so long as that of Kings River canals, and is largely dependent on the conditions of the diversion of water at the head of St. Johns River, where conflicting interests of different irrigated regions have given rise to repeated modifications of natural channels. Ordinarily the flow of Settlers and Lakeside canals commences in January and continues to the end of June.

The total amount of water supplied to the Mussel Slough country by the canals above enumerated is sufficient to cover the entire area under these canals and their branches to an average of several feet per annum. It was sufficient in 1885 to cover the land which was then in actual cultivation in this part of the Kings River delta to a depth of about 4 feet.

Irrigation on a noteworthy scale commenced in 1870 in the Mussel Slough country when the Lower Kings River Canal was constructed. The construction and extension of the several other canals quickly followed. There has been but little extension of the canal system since 1880.

Each canal project (with the possible exception of the Mussel Slough Canal) had its origin with the settlers who needed water. The sole consideration in each case seems to have been the securing of a fairly reliable water supply at reasonable cost for use upon the lands of the projectors of each enterprise. This circumstance will account for the apparent duplication of canals; for, as the irrigated area was extended and additional lands were settled, it was but natural for the landowners of the new settlements to construct new canals and to control independent canal works. The seven canals that are or have been in use in the Mussel Slough country could well be replaced either by one main canal from Kings River or, perhaps better, by one such canal and one smaller one from Kaweah River.

The canals distribute water throughout the delta in a network of branches and natural channels, often so intertwined that large areas are benefited by the water of several canals at the same time. It happens, too, that lands whose owners have no claim upon water in any canal are here and there so favorably located that they are irrigated without cost to owners by the canals and ditches of their neighbors.

Method of irrigation.—The rainfall in the Kings River delta is only 9 inches per annum. Irrigation is necessary for the successful cultiva-

tion of all soil products. Cereals and alfalfa were practically the only cultures from 1870 until 1884. More attention is now given to fruit raising, to the cultivation of the grape, and to diversified farming.

To prevent wholesale inundation of south-side delta lands a levee is maintained along the south bank of the main channel of Kings River.

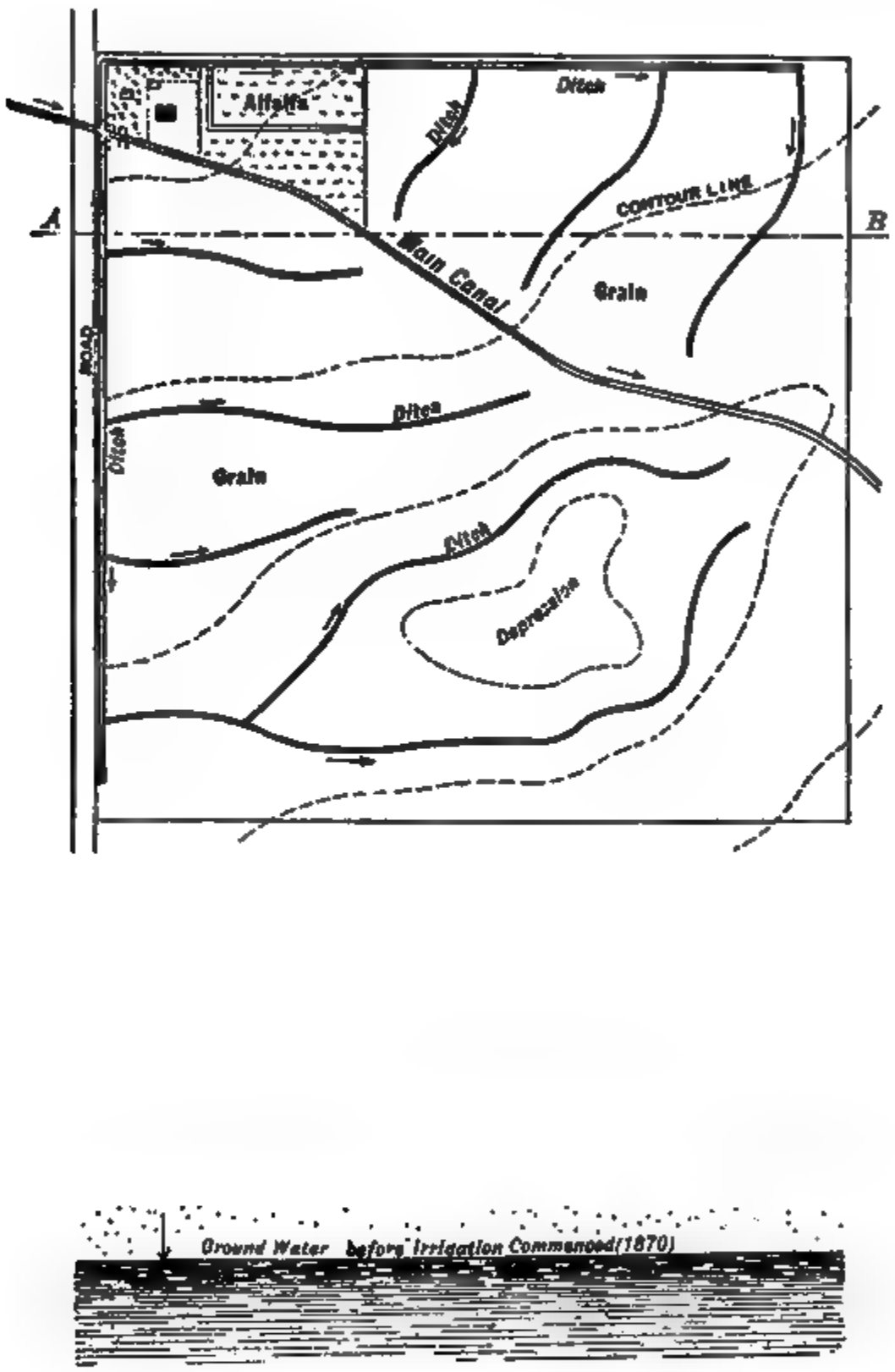


FIG. 21.—Irrigation by filling subsoils with water, Mussel Slough country.

The inflow of irrigation water into the district is controlled by means of regulators in the heads of the principal canals. The flow of water in some of the main canals and in most canal branches is sluggish, water being generally held at a very light grade, often by use of check weirs.

Water is rarely spread over the surface of the ground. This is done only in seasons when the supply to the canals comes late, or when gophers become too numerous in the alfalfa fields. The ordinary method of irrigation may be described as a periodical saturation of subsoils. From the time that water becomes available in the spring the canals and their branches, as well as small irrigating ditches, are kept as full of water as the available supply will permit. The water which sinks into the porous soils gradually saturates subsurface strata, bringing ground water within reach of plant life and sometimes even out upon the surface. Irrigation is considered complete when the water table has risen to within 3 to 4 feet of the ground's surface, as this will insure a thorough moistening of surface soils by capillary attraction.

Throughout the Mussel Slough country the range of water-table elevation is clearly defined. It drops from its general position at the height of the irrigating season, about 4 feet below ground, to a greatest depth of 7 to 10 feet during the fall and winter months. This fluctuation is the direct result of irrigation, and it is more or less rapid in the different portions of the district according to the character of the soil, the distance between irrigating ditches, and other local conditions.

Locally this method of irrigation is rarely understood. It is referred to as irrigation by percolation, and according to the ordinary conception of the method there should be a direct lateral horizontal percolation of water through surface soils.

For the irrigation of grain or alfalfa it is customary, if the land be at all uneven on the surface, to carry distributing ditches along the highest points of the ground. From these the water is drawn into irrigating ditches 3 to 6 feet wide and 1 to 2 feet deep, which are cut with a slight fall out upon each side from the distributing ditches, and are from 300 to 600 feet apart. These irrigating ditches are either temporary or permanent. If temporary, they are usually plowed in after each irrigation and reopened for the next one. When orchards and vineyards are to be irrigated the ditches are constructed in straight lines between the rows of trees or vines, whenever such arrangement is possible.

Simple as this method of irrigation may appear, it has its disadvantages, not the least being directly due to the preponderance of the upward movement of the moisture in the surface soils. The water, before moving upward, often passes for long distances through permeable subsoils. Where ground is wet by irrigation 150 feet from the nearest ditch, the water reaching it must have passed at least 150 feet through porous strata, besides the distance it may have had to sink originally and the height it again rose to reach the surface soil. Water thus permeating, at times saturating, soils which are rich in salts ordinarily classed as alkaline, is sure to dissolve more or less of these mineral substances, and it will retain some of them in solution until sooner or later it arrives at the surface and there evaporates. Though the

quantity of these salts in solution may be very small, they will, if present at all, ultimately become apparent at the surface, because the moisture there evaporating is periodically replaced from below, not from above. Careful inquiry establishes the fact that some injury has already resulted from this cause; that many fields whose soil a few years ago was of excellent quality now have soil too strongly alkaline to produce good grain crops, and that even alfalfa fields have been injured. There seems to be no limit to the extent of damage which may result from this cause unless the method of irrigation be properly modified.

The simplest remedy for this evil, suggested by its cause, is to secure a preponderance of downward motion of moisture. If this can be done, more of the salts leached out of the soils by water will move downward away from the surface than upward toward it. The quantity of alkali at the surface, where it is most injurious, will necessarily be decreased. The remedy will be made still more effective if subdrainage be resorted to—if the water descending to the subsoils through the surface soil be in large part carried off in deep drainage channels.

It is not without interest in this connection to note the effect of rain on those spots of the plains where alkali is seen on the surface as an efflorescence or has formed a crust. A gentle rain, with no run-off from the surface, wetting the ground to the depth of a foot or two, may dissolve the efflorescence and all alkaline crusts, carrying the salts downward into the soil. But they return to the surface with the returning moisture, all of which is ultimately evaporated. A long-continued rain may send water vertically downward to ground water. It may thus cause a permanent reduction of alkaline salts at the surface. Sudden heavy rainfall, dissolving the salts on the surface, may carry them into natural drainage channels and permanently remove them from the soil.

It remains to be said that the accumulation of alkali at the surface is retarded by thorough tillage and occasional deep plowing. By tillage the capillary upward movement of moisture is checked; there is less evaporation from the surface layer of soil; consequently, the amount of alkali accumulating at the surface is minimized. Deep tillage buries the surface salts, removing them for a time at least from that layer of the soil where they are most injurious.

The cost of preparing land for irrigation in the Mussel Slough country has been relatively small because the surface required no shaping and only limited areas have been arranged for flooding in checks. The cost of constructing the small irrigating ditches has been variously estimated at from $2 to $4 per acre, and the annual expense of irrigating at from 25 cents to $1 per acre.

INDEX.

Page.

Alfalfa, methods of irrigating 83, 84, 90
Alta irrigation district, work in..... 52–57
Bacon & Crossmore Canal, description of.. 29–30
Bahwell Ditch, description of 33
Barton Ditch, description of..... 57
Bliss & Hyde Ditch, description of..... 25
Bostwick Cut, description of 33
Brown Ditch, description of..... 25
Burch Ditch, description of..... 32
Catron Ditch, description of..... 25
Cameron Creek, course of 13
Cameron Creek Company, operations of.... 29
Centerville Ditch, description of..... 47–48
Centerville & Kingsburg Canal, description of 50–52, 75–76
Chatten Ditch, description of..... 31
Cole Slough, course of..... 41–42
Consolidated Peoples Ditch, description of. 22–25
Crescent Canal, description of..... 62
Cross Creek, course of..... 13
Crowley & Mehrtens Ditch, description of.. 34
Curtis Ditch, description of 17
Curtis & Lindsey Ditch, description of..... 16
Cutler & Higgins Ditch, description of..... 31
Davis Ditch description of..... 25
Deep Creek course of 12, 14
Dennis & Jordan Ditch description of 57
Duty of water, observations on..... 79–85
Elbow Ditch No. 1, description of..... 16
Elbow Ditch No. 2, description of..... 16
Emigrant Canal, description of..... 57–58
Enterprise Ditch, description of..... 43
Evans Ditch, description of 32
Evans & Turner Ditch, description of..... 32
Evaporation and seepage, loss of water by.. 74–78
Extension Ditch, description of 25–26
Farmers Canal, description of..... 27–28
Fowler Switch Canal, description of..... 48–50
Fresno Canal, description of..... 43–47
Fresno Plains, canal system of..... 73–74
  description of 71–73
  effect of irrigation on water table in.... 78–79
  loss of water by evaporation and seepage in..... 74–78
  methods of irrigation and duty of water in 79–85
Fulgham Ditch, description of 33
Glenn Ditch, description of..... 57
Goshen Ditch, description of 20–21
Grant Canal, description of 58–62
Hall, W H., cited 11, 39
Hamilton Ditch, description of..... 22

Page.

Hayes Lower Ditch, description of..... 21
Hayes Upper Ditch, description of..... 20–21
Hicks & Weston Canal, description of 20
Irrigation, effect on water table of..... 78–79
  methods of..... 35–38, 79–85, 88–91
Jacobs Canal, description of..... 69
Jennings Ditch, description of..... 20
Judd Ditch, description of 30–31
Kaweah Canal, description of 26–27
Kaweah River, canals and ditches from.... 14–35
  hydrography of 11–14
Kaweah and Mill Creek Water Company, operations of..... 31
Ketchum Cut, description of..... 34
Kincaid Ditch, description of 57
Kings River, canals and ditches from..... 42–69
  course of..... 40–41
  hydrography of 39–42
Kings River and Fresno Canal, description of 42–43, 74–75
Laguna de Tache Canal, description of..... 58
Laguna de Tache Rancho, irrigation on ... 58–59, 61, 86–87
Lakside Ditch, description of 18–20
Last Chance Ditch, description of..... 65–67
Lee & Thompson Ditch, description of..... 25
Liberty Canal, description of..... 58
  irrigation from..... 86
Longs Canal, description of 33
Lower Kings River Canal, description of .. 67–69
Matthew Ditch, description of 16–17
Mill Creek, course of..... 13
Mill Ditch, description of 33
Millrace Canal, description of..... 58
  irrigation from..... 86
Modoc Canal, description of..... 20
Morrow Ditch, description of 57
Mussel Slough country, irrigation in..... 87–91
Mussel Slough Ditch, description of 64–65
Newell, F. H., letter of transmittal by..... 9
Oaks Ditch, description of..... 31–32
Ogden Ditch, description of..... 21–22
Orchards, methods of irrigating..... 83, 84, 86
Outside Creek, course of 14
Packwood Creek, course of..... 13
Packwood Creek Canal, description of 29–30
Pennebaker Ditch, description of 25
Peoples Ditch, description of..... 62–64
Pogues Lower Ditch, description of..... 21
Pogues Upper Ditch, description of..... 21
Reeds Ditch, description of 58
Rhoads Canal, description of..... 69

	Page.
Rice Ditch, description of	25
Rocky Ford Ditch, description of	29
Rodgers Ditch, description of	20
St. Johns Channel, course of	12, 13
Seepage and evaporation, loss of water by	74–78
Selma irrigation district, situation of	52
Settlers Ditch, description of	17–18
Seventy-six Canal, description of	52–57
Soils, nature of	37, 72, 85, 87
Sunset irrigation district, work in	69–70
Swanson Ditch, description of	25
Sweem Ditch, description of	48
Teague Ditch, description of	25
Trees and vines, method of irrigating	83, 84, 86
Tulare irrigation district, work in	34–35
Tulare Canal, description of	28–29
Uphill Ditch, description of	17
Venice Ditch, description of	16
Vines and trees, methods of irrigating	83, 84, 86
Visalia Creek, course of	12, 13
Wahtoke Creek, course of	42
Wahtoke Reservoir, map of	53
Water, duty of	79–85
Water table, effect of irrigation on	78-79
Watson Ditch, description of	32–33
Weston Ditch, description of	17
Wildflower, irrigation near	85–86
Wutchumna Canal, description of	14–16

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CHARLES D. WALCOTT, DIRECTOR

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BY

CARL EWALD GRUNSKY

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CONTENTS.

	Page.
Letter of transmittal	7
San Joaquin River	9
Hydrography	9
Canals and ditches	13
Upper San Joaquin River Canal	13
Madera irrigation district	14
Chowchilla Canal	15
San Joaquin & Kings River Canal	18
Posey Slough or Dos Palos Canal	24
Temple Slough	24
Sanjon de Santa Rita	24
Blyth Canal	25
East Side or Stevenson-Mitchell Canal	25
Fresno River	26
Hydrography	26
Canals and ditches	27
Madera Canal (Fresno River Dam and Canal Company's Canal)	27
Adobe Ranch Ditch	31
Chowchilla River	31
Hydrography	31
Canals	31
Kohler, West & Minturn canal system	31
Buchanan Reservoir project	32
Merced River	33
Hydrography	33
Canals and ditches	34
Merced or Crocker-Huffman Canal	34
Merced River Bottom canals	37
Merced Falls mills	37
Merced Falls Ditch	37
Murray Mill Ditch	37
Snelling Ditch	38
Montgomery & Anderson Ditch	38
Ingalsbe Slough	38
Scott Ditch	38
Dean Ditch	38
Old River	38
Feldhaus & Reed Ditch	39
Hamlin or Millrace Ditch	39
Griffith & Shaver Ditch	39
Methods of water diversion and use	39
Tuolumne River	40
Hydrography	40
Canals and ditches	43
Lagrange Ditch	43
Wheaton Ditch	44
Lagrange Dam	45

Tuolumne River—Continued. Page.
Canals and ditches—Continued.
Turlock irrigation district 47
Modesto irrigation district 49
Stanislaus River 50
Hydrography 50
Canals and ditches 52
Stanislaus & San Joaquin Canal 52
Knights Ferry & Table Mountain Ditch (Pentland Ditch) 55
Oakdale Canal 56
Mokelumne River 56
Hydrography 56
Canals and projects 57
West-side creeks and other streams of San Joaquin Valley 58
Index 59

ILLUSTRATIONS.

PLATE I. Steamboat chute, San Joaquin River, at head of San Joaquin & Kings River Canal: *A*, As seen from below; *B*, As seen from above 20
II. Regulator in San Joaquin & Kings River Canal: *A*, As seen from above; *B*, As seen from below 22
III. Blyth Canal: *A*, Head at San Joaquin River; *B*, Nine-foot cut 24
IV. East side of San Joaquin Valley from Chowchilla River to Merced River 32
V. Dam across Merced River for Crocker-Huffman Canal 34
VI. Regulator in Crocker-Huffman Canal 34
VII. Tunnel No. 2 on Crocker-Huffman Canal 36
VIII. Crocker-Huffman Canal near head, looking down 36
IX. Inlet to Merced Reservoir, Crocker-Huffman Canal 38
X. Lagrange Dam during construction: *A*, As seen from front; *B*, Abutment 44
XI. Lagrange Dam: *A*, Nearing completion; *B*, At time of high water .. 46
FIG. 1. Discharge of San Joaquin River at Herndon, California, 1895–96 12
2. Head of Upper San Joaquin River Canal, on San Joaquin River, 1883. 13
3. Plan and section of Chowchilla Canal regulator 16
4. Head of San Joaquin & Kings River Canal 18
5. Details of head works of San Joaquin & Kings River Canal 19
6. Brush dam across San Joaquin River at head of San Joaquin & Kings River Canal 20
7. Head of Fresno River Canal 27
8. Head of Adobe Slough 30
9. Water diversion by Kohler, West & Minturn Canal 32
10. Discharge of Tuolumne River at Modesto, California, 1895–96 42
11. Discharge of Tuolumne River at Lagrange, California, 1895–96 43
12. Plan of Lagrange Dam 45
13. Section of Lagrange Dam 46
14. Discharge of Stanislaus River at Oakdale, California, 1895–96 52

LETTER OF TRANSMITTAL.

DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
DIVISION OF HYDROGRAPHY,
Washington, July 15, 1898.

SIR: I have the honor to transmit herewith a manuscript entitled Irrigation near Merced, California, by Mr. C. E. Grunsky, and to recommend that it be published as one of the series of pamphlets on Water Supply and Irrigation. This is the third of three papers relating to irrigation in San Joaquin Valley, the other two being Nos. 17 and 18 of the series. This paper describes the irrigation systems deriving their water supply from San Joaquin, Chowchilla, Merced, Tuolumne, Stanislaus, and Mokelumne rivers.

Very respectfully,

F. H. NEWELL,
Hydrographer in Charge.

HON. CHARLES D. WALCOTT,
Director United States Geological Survey.

IRRIGATION NEAR MERCED, CALIFORNIA.[1]

By C. E. GRUNSKY.

SAN JOAQUIN RIVER.

HYDROGRAPHY.

San Joaquin River enters San Joaquin Valley from the east at a point about 20 miles northeast of Fresno, flows southwesterly 55 miles to the valley trough, and, entering the lowlands of the Fresno Slough country, turns at Las Juntas abruptly to the northwest and becomes the main drainage channel of the valley. For 40 miles below Hamptonville, the point at which the river enters the main valley, its course lies through narrow strips of bottom land hemmed in by bluffs rising to the plains above. These bluffs are generally one-half mile to a mile apart and descend abruptly toward the river from a very smooth-surfaced plain. They gradually decrease in height toward the west, their height being about 60 feet near the eastern edge of the valley and 40 feet near Herndon. Before the river reaches Las Juntas, 20 miles by river below Herndon, the bluffs have disappeared entirely, and the flood waters of the river sweep across country to the southwest into Fresno Swamp and to the northwest in a direction down the valley parallel with the river.

Bottom lands of small extent flank the river between its bluffs, but have remained unirrigated. The upland of the main valley plain is so high above the river near the eastern border of the valley that canals to command the upland would be very costly, and none have been constructed, though several have at various times been projected. The diversion of water for irrigation is confined to that portion of the river lying in or near the main valley trough.

The area of the river drainage basin above the point where it breaks from the Sierra Nevada is 1,637 square miles. This entire area is mountainous. It extends eastward to the summit of the Sierra Nevada, 70 miles of this summit, measured in a direct line, being the eastern limit of the river's drainage basin.

The river is ordinarily at its highest stage in the spring months, generally in May and June; but winter freshets are not uncommon, and extreme floods, such as those of 1861–62 and 1867–68, have occurred in winter. The flow of the river at Hamptonville, near the eastern border of San Joaquin Valley, was approximately determined by the State

[1] See introductory remarks in Water-Supply Paper No. 17, p. 13.

engineer of California for the years 1878 to 1884.[1] A mean monthly flow for November of 378 second-feet and a mean monthly flow for June of 10,150 second-feet were the extremes indicated by these measurements.

The river is ordinarily at a low stage from September to the end of December. It is at a medium stage, with a flow in excess of 1,000 second-feet, from January to March and in July and August. It is high from April to July. These periods are, however, to be taken only as a general guide, because the flow of this stream varies within wide limits, according to the varying conditions of rainfall and temperature of each season.

The Southern Pacific Company have maintained daily readings of gage height on this river since 1879 at their bridge half a mile north of Herndon and 12 miles north of Fresno. Since 1895 the United States Geological Survey has been taking measurements of discharge from the wagon bridge near by. The results of these measurements are published in various reports of the Survey.[2]

The following facts in regard to the flow of the river are brought out:

1895. Maximum discharge, May, 19,960 second-feet; minimum, September, October, November, and December, 260 second-feet; average for the year, 3,791 second-feet.

1896. Maximum discharge, May, 18,800 second-feet; minimum, September and October, 80 second-feet; average for the year, 2,756 second-feet.

1897. Maximum discharge, May 24, 18,600 second-feet; minimum, December 23, 60 second-feet; average, 3,105 second-feet.

Estimated monthly discharge of San Joaquin River at Herndon, California.[3]

[Drainage area, 1,637 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth in inches.	Second-feet per square mile.
1895.						
January	11,225	1,260	2,881	177,102	2.029	1.760
February	8,500	909	2,568	142,590	1.634	1.569
March	9,318	1,554	2,779	170,840	1.957	1.697
April	9,863	3,354	5,884	316,600	3.626	3.564
May	19,960	5,100	13,124	807,000	9.243	8.017
June	14,585	7,250	10,674	599,404	6.866	6.520
July	8,000	2,148	4,528	278,410	3.189	2.766
August	2,301	793	1,417	87,104	.997	.866
September	8,500	260	1,085	64,567	.740	.663
October	1,260	260	420	25,846	.296	.257
November	426	260	362	25,562	.247	.221
December	677	260	373	22,905	.262	.228
The year	19,960	260	3,791	2,717,930	31.086	2.334

[1] See Physical Data and Statistics, Wm. Ham. Hall, State engineer of California, 1886, pp. 449, 476.

[2] Twelfth Ann. Rept., Part II, 1891, p. 321, Pl. LXXXIV; Bull. No. 131, 1895, p. 81; Bull. No. 140, 1896, p. 290; Eighteenth Ann. Rept., Part IV, 1897, p. 385; Water-Supply and Irrigation Paper No. 11, 1897, p. 91; Water-Supply and Irrigation Paper No. 16, 1898, p. 190.

[3] In using results shown in these tables of discharge, some allowance must be made for uncertainty as to the permanency of stream cross sections on which rating tables were based. A slight change in absolute elevation of river bed at the rating station, if known, would modify the rating table, particularly for low-water stages. Lack of information on this point may lead to erroneous conclusions. The flow of San Joaquin River at Herndon has probably never dropped to 60 cubic feet per second.

Estimated monthly discharge of San Joaquin River at Herndon, California—Continued.

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth in inches.	Second-feet per square mile.
1896.						
January	12,800	250	2,119	130,335	1.49	1.29
February	1,750	950	1,177	67,696	.77	.72
March	12,176	1,180	2,612	160,649	1.84	1.60
April	5,648	1,920	2,675	159,192	1.83	1.64
May	18,800	2,560	5,394	331,700	3.81	3.30
June	16,920	6,544	11,799	702,106	8.00	7.21
July	8,080	1,600	4,177	256,865	3.04	2.55
August	1,300	700	1,048	64,463	.74	.64
September	1,180	80	534	31,817	.37	.33
October	700	80	167	10,275	.12	.10
November	2,390	430	697	41,492	.48	.43
December	1,750	430	666	40,957	.47	.41
The year	18,800	80	2,756	1,997,547	22.96	1.69
1897.						
January	1,180	535	655	40,275	.46	.40
February	15,660	1,180	2,598	144,286	1.66	1.59
March	4,600	1,675	2,325	142,960	1.64	1.42
April	11,708	2,305	6,541	389,216	4.46	4.00
May	18,600	9,565	13,545	832,855	9.54	8.27
June	12,332	2,390	5,862	348,812	3.98	3.57
July	4,300	1,300	2,493	153,290	1.75	1.52
August	1,300	590	898	55,216	.63	.55
September	535	105	227	13,507	.16	.14
October	820	105	279	17,155	.20	.17
November	4,300	120	872	51,887	.59	.53
December	4,000	60	968	59,520	.68	.59
The year	18,600	60	3,105	2,248,979	25.75	1.90

For several miles below the western base of the Sierra Nevada foothills ledges of rotten granite appear in the bed of the river; these are often covered to considerable depth by sand and gravel bars. The river channel is here generally 300 to 500 feet wide. From Hamptonville to Herndon it falls 89 feet in 20 miles; thence to Las Juntas about 36 feet in a distance of about 36 miles. Below Herndon the low-water flow is between sandbars. After passing Las Juntas, where the river is joined by Fresno Slough, it becomes the main drainage line of San Joaquin Valley. It has not, however, been a rapid land builder, and the elevation of river banks is but slightly greater than that of the general surface of the submersible area which flanks the stream.

From Las Juntas to the head of Old River, where the river bifurcates, the distance in an air line is 87 miles. The river between these points has a length of 146 miles. Its average width is 400 feet, and the depth of its channel, from top of natural banks to river bed, is 12 to 18 feet. There is a slight slope of bank lands away from the river, except at a few points, where the river impinges upon spurs of upland that extend eastward from the Coast Range foothills, notably at Grayson and near San Joaquin. The river bottom is generally clean sand, but a firm clay is here and there exposed. River banks are of quite firm alluvial material, showing but little tendency to cave. They are lightly fringed with willows and cottonwoods and occasionally oaks.

The land upon either side of the river subject to periodical flooding

is generally open country, throughout which clumps of willows mark the alignment of sloughs, as the overflow channels from the river are called. Tule grows in spots where high bank lands along the sloughs or river have penned in water or sufficiently retarded drainage to keep the surface moist throughout the year. Oaks are dotted over some portions of this region, but rarely appear in dense groves. The main east-side and west-side plains have been described in Water-Supply Paper No. 17, on page 15.

FIG. 1.—Discharge of San Joaquin River at Herndon, California, 1895–96.

CANALS AND DITCHES.

Upper San Joaquin River Canal.—This work has not been a success. The construction of the canal commenced in 1879. It was pushed for some time, until about $85,000 had been expended on it; several years then passed, during which little or no work was done. A new company finally took hold of the enterprise, expending about $300,000 on a dam at the head of the canal and on the main canal above Herndon. Their dam was completed in the fall of 1883 and was maintained

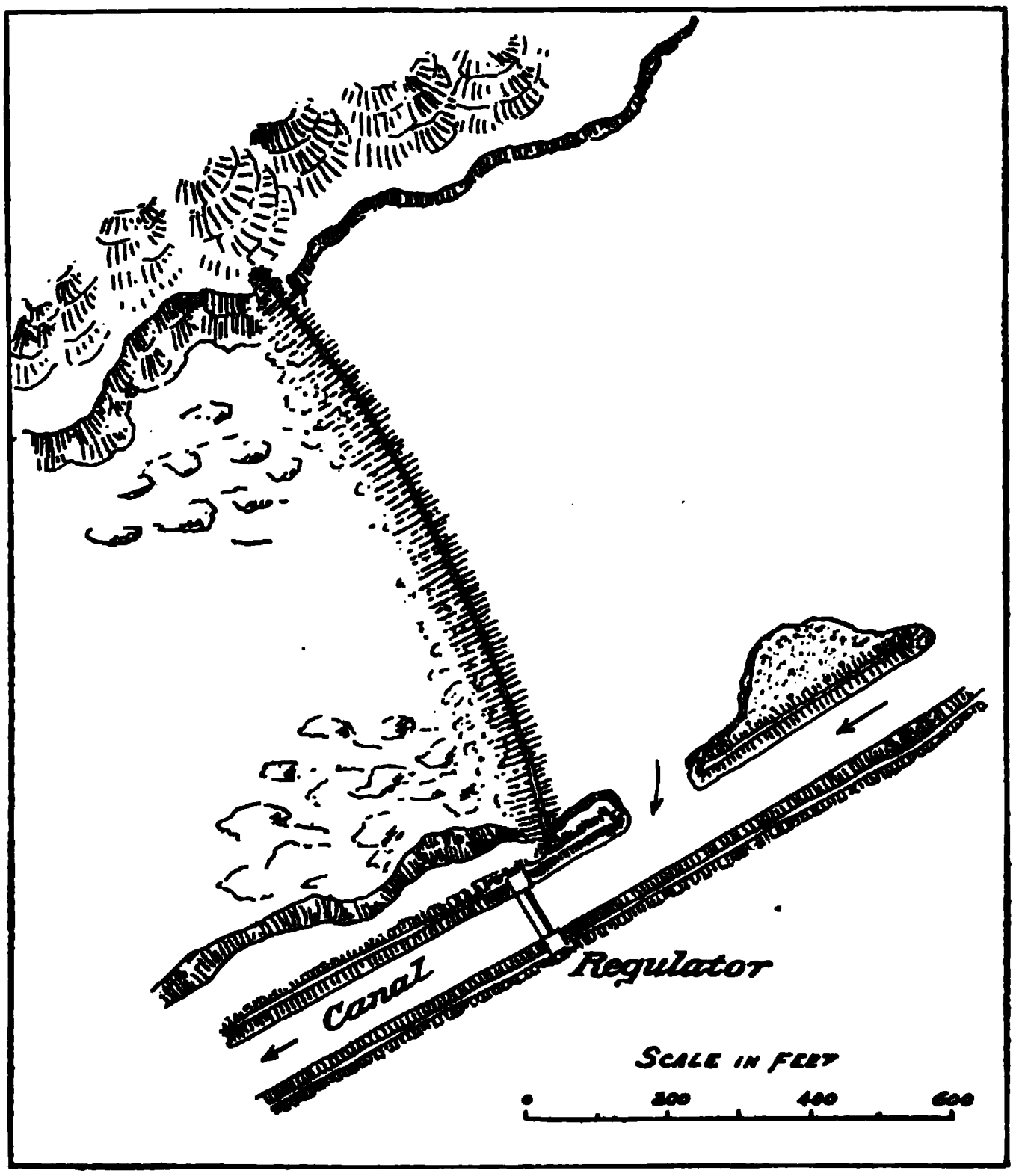


FIG. 2.—Head of Upper San Joaquin River Canal, on San Joaquin River, 1883.

with difficulty for several years, during which time a little water was forced through the canal and out upon the upland near Herndon. About 1887 the work was abandoned.

The head of the canal is about one-half mile below Hamptonville, at a point where the river is nearly 900 feet wide. The river bottom is sand, about 20 feet deep, resting upon a rotten granite formation. A loose-rock diverting dam was constructed at this point to a height of about 8 feet above low water. It was proposed to allow the river to flow over this from bank to bank. The material used for the dam was rock as quarried from a spur of granite, cobbles, and gravel. All material was

dumped into place from small cars. No attempt seems to have been made to secure large blocks of stone, and all rock fragments ordinarily classed as quarry waste went into the structure. The largest stone (maximum size about 1¼ cubic yards) was dumped downstream to form a face that should resist the force of overfalling water. As the lower face rock dropped into place the river cut out the sand in its bed, thus permitting at least the toe of the structure to find a solid formation. The upstream face was formed of fine quarry waste, cobbles, and gravel. Trestle piles which carried the car track were allowed to remain in place and the downstream crest edge of the structure was protected by three layers of planking. Other expedients, such as extending an iron plate over the upper portion of the downstream slope for its protection, were tried, but experience soon demonstrated the difficulty of maintaining a loose-stone dam in a river of considerable flow. Even the later reconstruction of the downstream face of the dam with large blocks of stone, hand laid, and its partial protection with fascines could not make the structure permanently secure and the river's freshets repeatedly cut out sections of it.

Experience with the canal itself was equally unfortunate. Its course for several miles is along and across the river bottoms, thence for 9 miles it hangs on the steep descent or bluff, from south-side upland to river, and finally cuts out to the higher level of the upland a few miles above Herndon. Near its head the canal has a bed width of 75 feet. Its total fall in the first 4 miles does not exceed 1 foot. Along the bluff it received somewhat irregular dimensions. It was intended to carry water 5 feet deep. Its bed width was generally 24 feet, side slopes 3 to 1, and its gradient one-quarter to 1 foot fall to the mile. It was endeavored to make sidehill cutting supply material for an outer levee, whose slope away from the canal was the natural slope of the material used in its construction, generally between 1½ to 1 and 2 to 1. Some of the excavated material was removed by blasting, being in firm layers of very hard clay or ashy sandstone. These firm materials, alternated with soft ashy deposits or a reddish loam material, did not make a safe levee, and great trouble was experienced in making this levee hold water.

Water was furnished through the canal long enough to encourage some tree planting and diversified farming, but not much progress had been made when the canal fell into disuse.

Madera irrigation district.—This irrigation district is located on the east-side plain of San Joaquin Valley, to the north of San Joaquin River. The district was organized in 1888 and was to be supplied with water from San Joaquin River. Notwithstanding active opposition, the necessary bonds were voted and the legality of the district organization was affirmed by the courts. It was proposed to take water from the north side of San Joaquin River near the point where it leaves the hills, but no construction work was done. Operations were blocked

by legal proceedings, and after many long delays it was decided to disorganize, which has been done. The district had an area of 305,000 acres, and the amount of bonds voted for construction of works was $850,000.

Chowchilla Canal.—This canal, which was constructed in 1872, has its head on the north side of San Joaquin River about 8 miles by river above Las Juntas. Its course is slightly west of north, almost parallel with the main drainage of the valley, and for a distance of over 20 miles it commands a strip of land averaging 5 miles in width, which is bordered on the west by San Joaquin River.

The river at the head of the canal lies in several channels, one of which sends off a branch toward the north, known as Lone Willow Slough. The river banks at the head of this slough rise about 15 feet above the low-water plane. By deepening the slough and constructing a gate in it, near its head, it was converted into a section of the canal, and from it, about 2 miles below, water was turned into the artificial canal. The canal was made 30 feet wide on the bottom and 2½ feet deep near the point where it leaves Lone Willow Slough. But these dimensions are maintained for 3 to 4 miles only. The width is then gradually reduced to 25, to 20, and finally to 15 feet. In its northerly course of nearly 30 miles the canal follows a grade line having a fall of 6 inches to the mile.

Mr. J. D. Schuyler, as assistant State engineer in 1879, describes the difficulties of canal construction and the canal head gate as follows:[1]

> The total cost of the canal was, in round numbers, $100,000.[2] The tough character of the excavation, the greater portion of the distance rendering the free use of blasting powder necessary, greatly increased the cost over that of ordinary earthen channels of like dimensions.
>
> The treacherous character of the quicksand bed at the head of the canal has made it an exceedingly difficult task to construct a head gate that would withstand the action of floods. For four successive seasons after the building of the canal the head gate was washed out, and as often replaced by a new structure on a different plan.
>
> In the fall of 1877 the present structure, which has withstood severe tests, and gives every evidence of permanence, was built. As this structure has some novel features, and its plan is indorsed by its success, it deserves a brief description. The use of sheet piling, generally considered indispensable to the safety of structures of this kind, was in this instance abandoned. The foundation was prepared by spreading a layer of loose sandstone, one or two feet thick, evenly laid on the quicksand. Upon this a floor of 2-inch plank, without sills, was laid across the axis of the canal, to which was spiked another layer of plank laid lengthways. This floor was placed 6 feet below the level of the bed of the river, and upon it was built the structure of 10 by 10 timbers, having a length of 60 feet, a width of 13 feet, and a height of 10 feet of clear waterway. The whole was weighted with an embankment of earth, 10 feet high, placed on top of the structure, the weight exceeding 500 tons. The sluiceways or regulating gates were placed 5 feet from the upper end of the floor, the space of 5 feet in front being occupied by a box of heavy timbers filled with rock and floored over, the top being 1 foot below the bed of the

[1] See Report of State Engineer, 1880, Wm. Ham. Hall, Part IV, Appendix, p. 176.

[2] This is believed to be an over estimate. The original total cost of the main canal was probably nearer $50,000 than $100,000.

river. The water comes into the canal therefore with a free overfall of 5 feet. In lieu of heavy solid regulating gates which are difficult to raise and lower, loose planks 5 feet long placed in grooves in the vertical posts are used. They are removed by a double hook which engages on an iron pin passing through the planks and projecting two or three inches on each side. A rope and windlass assists in raising the planks to the top. The cost of this structure was $3,200, of which $2,000 was expended in laying the foundation.

There is no weir or dam in the river to aid in accomplishing diversion of water into the canal, but the canal bed is below the low-water plane of the river (reported to be 6 feet below), affording a fall from river to canal which insures it a full supply of water.

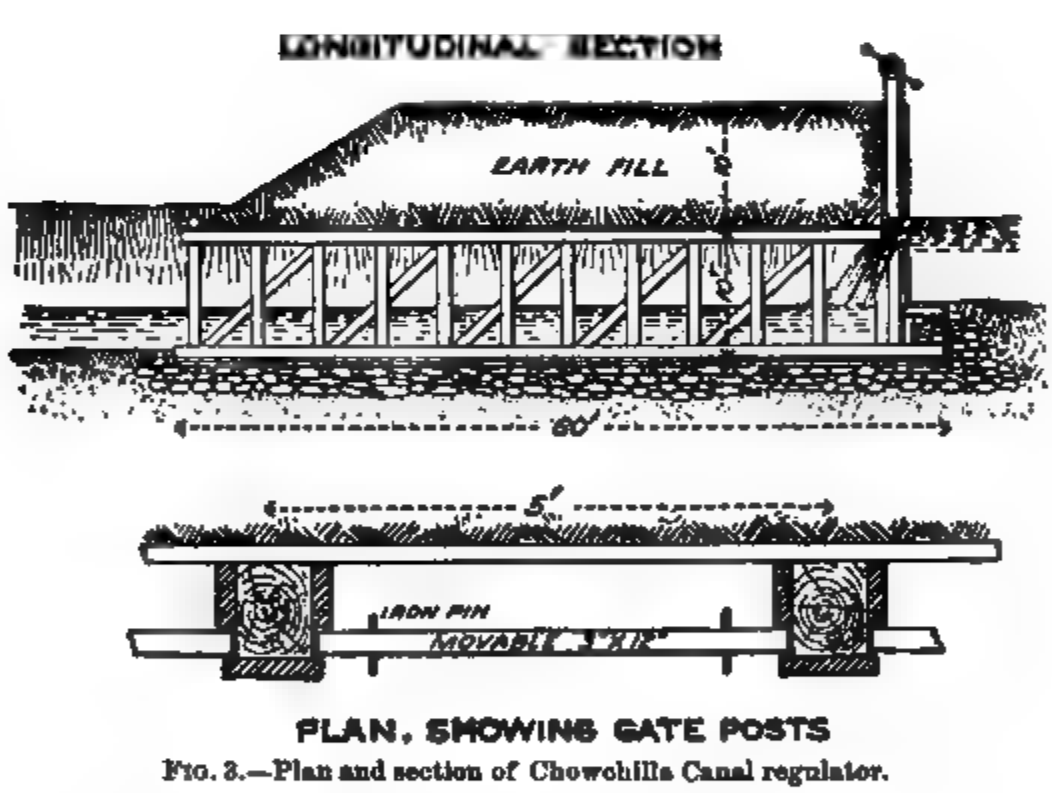


FIG. 3.—Plan and section of Chowchilla Canal regulator.

The head gate above described is located in Lone Willow Slough, about 100 feet from the river bank. A second regulator is maintained in the head of the artificial canal, and the lower portion of Lone Willow Slough is used as a channel for waste water.

The canal crosses the natural drainage of the east-side plain, a location which has at times made maintenance and repair expensive, owing to the frequent destruction of canal banks by the water reaching the canal from the east. At the crossings of Cottonwood Creek, Fresno River, Berenda Slough, and Ash Slough the canal is left open toward

the east, and an outlet gate in its west or lower bank permits the passage of the creek waters when they are swollen by freshets.

The canal is owned jointly by the Miller & Lux Company and the California Agricultural and Pastoral Association. The interests of the two concerns are equal to the point where the canal leaves the lands owned by the former; below that point the latter is sole owner.

The canal capacity near its head is from 100 to 200 second-feet. Its water is now used largely for the irrigation of alfalfa, although when first undertaken the work was intended principally for stock purposes. The place of use is on the Riverside and Columbia ranches of the Miller & Lux Company and on the Chowchilla Ranch of the California Pastoral and Agricultural Association. No water is sold from this canal, it being all required for use on the three tracts named.

The total area of alfalfa land now under irrigation is about 7,000 acres, nearly equally distributed to the three tracts named. On the Chowchilla Ranch works have recently been constructed for extensive irrigation of grass lands. These consist of high well-built levees extending from the high bank land of San Joaquin River eastward far out upon the plain. These levees, six in all, are about a mile apart, and each is equipped with a large so-called "stop gate." These gates are similar to the check weirs in ordinary use on large canals. The largest are 40 feet wide, and some of these are reported to have cost $1,500 each. Each of these gate structures supports a bridge. They are used to restrain water until the submersible area above each is covered with water, which then flows through the gate to the next tract to be inundated. For this grass-land irrigation the flow of the canal and the natural flow of the streams intercepted by it supplement the flow of the Blyth Canal, hereinafter referred to.

The method of irrigating alfalfa lands is by flooding in contour checks. The check levees on the Chowchilla Ranch were originally made high and had exceptionally steep side slopes. The areas of the compartments or checks ranged from 20 to 100 acres. They were altogether too large for the available water supply. It was at first attempted to make the gates through the check levees serve as roadways for teams and farming implements, but this idea soon proved impracticable. The advantage of reducing check areas and of making low flat levees has long been recognized by the managers of the property, and the original defects in the irrigation system have in a measure been remedied.[1] The Riverside Ranch receives its water through a branch canal which was constructed in 1884. This branch is taken out of Lone Tree Slough about 1½ miles below its head and closely follows the river. It has a length of about 8 miles. The soil on the Riverside and Columbia ranches is a heavy black loam. The original practice was to subdivide into irregular checks of 10 to 50 acres by means of high, steep levees. It was found necessary to make use of natural sloughs and waterways to carry off

[1] See Report of State Engineer, Wm. Ham. Hall, 1880, Part IV, Appendix, p. 177.

surplus waters from the many low spots, which, on account of the light slope of this section of the valley, could not otherwise readily be relieved of standing water. The gates in use in the irrigating ditches and to control the flow of water from one check into another are somewhat peculiar. They are built without the use of sheet piling or its equivalent and without wings, but seem to stand well in the firm soil.

After a number of years of experience the management of the Riverside and Columbia ranches has learned its lesson and the large checks are being subdivided. A few acres in each compartment are preferred, and levees are made low and broad, generally 18 inches high on a 12-foot base.

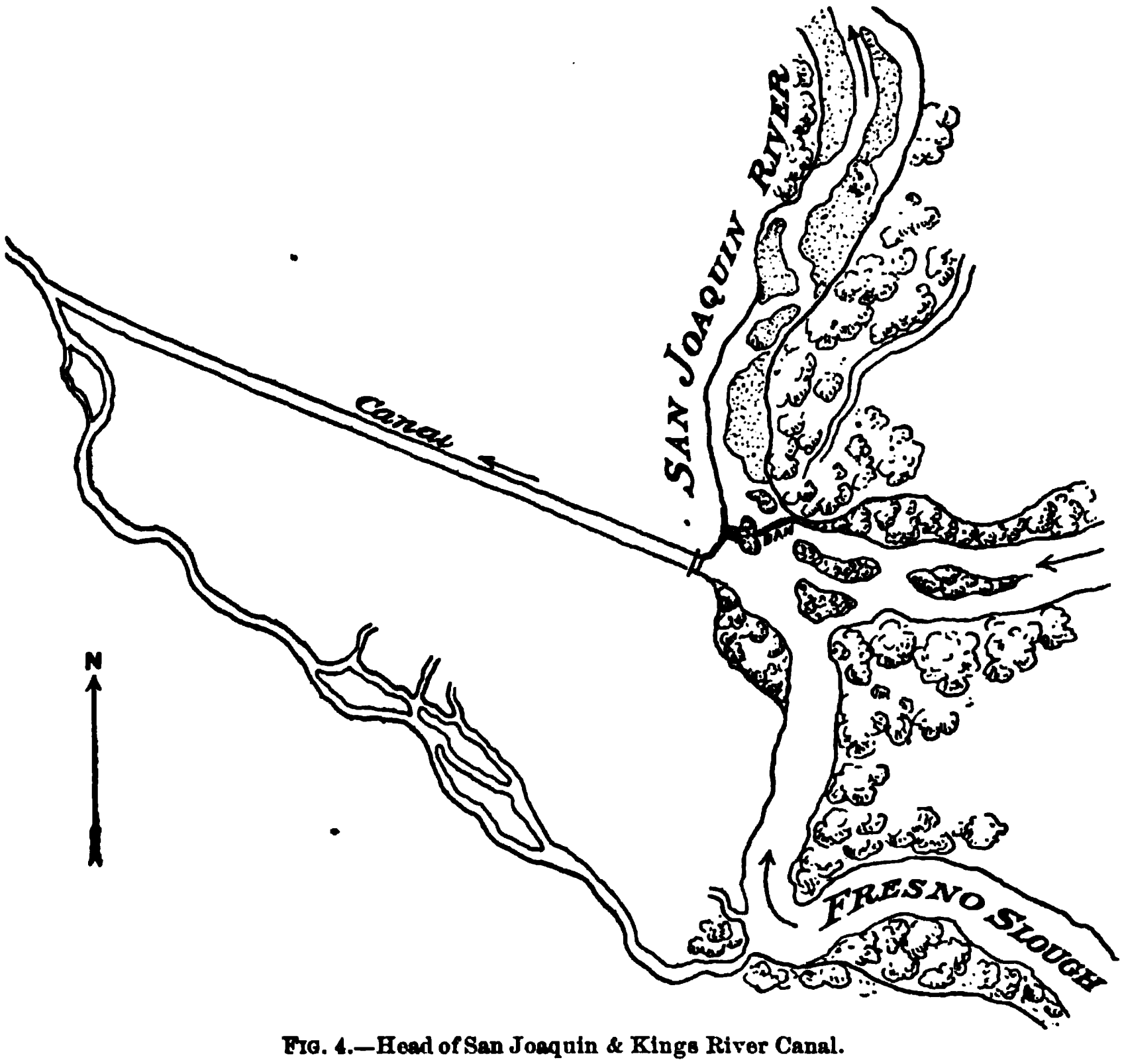


FIG. 4.—Head of San Joaquin & Kings River Canal.

The lands adjacent to this canal for about 15 miles of its length, intermediate between the Columbia and the Chowchilla properties, are practically worthless for agricultural purposes. The soil is shallow; it lies on a sandstone-like hardpan and can produce but a scant growth of grass.

San Joaquin & Kings River Canal.—This is one of the most important of the canals in San Joaquin Valley. It commands a large portion of the west-side plain. Its head is just below Las Juntas, the point where Fresno Slough unites with San Joaquin River, about 9½ miles above Firebaugh. At that point a small island divides the river into

two channels, of which the lesser one, about 50 feet wide, lies at the west. Into this lesser channel a structure with falling dam, 47 feet between side walls, has been built to facilitate the passage of steamboats. (See Pl. I.) In the other channel a brush diverting dam about 350 feet long is maintained, which holds water at all stages about 6 to 8 feet above the river's natural low-water plane. The inflow into the canal is controlled by means of a gate 47½ feet between walls, which is bridged over. The space between walls is subdivided by gate and bridge posts into six divisions, each of which can be closed by means of drop timbers. (See Pl. II.)

This regulating gate and the steamboat chute required much pile work and sheet piling to afford them support and protection. The

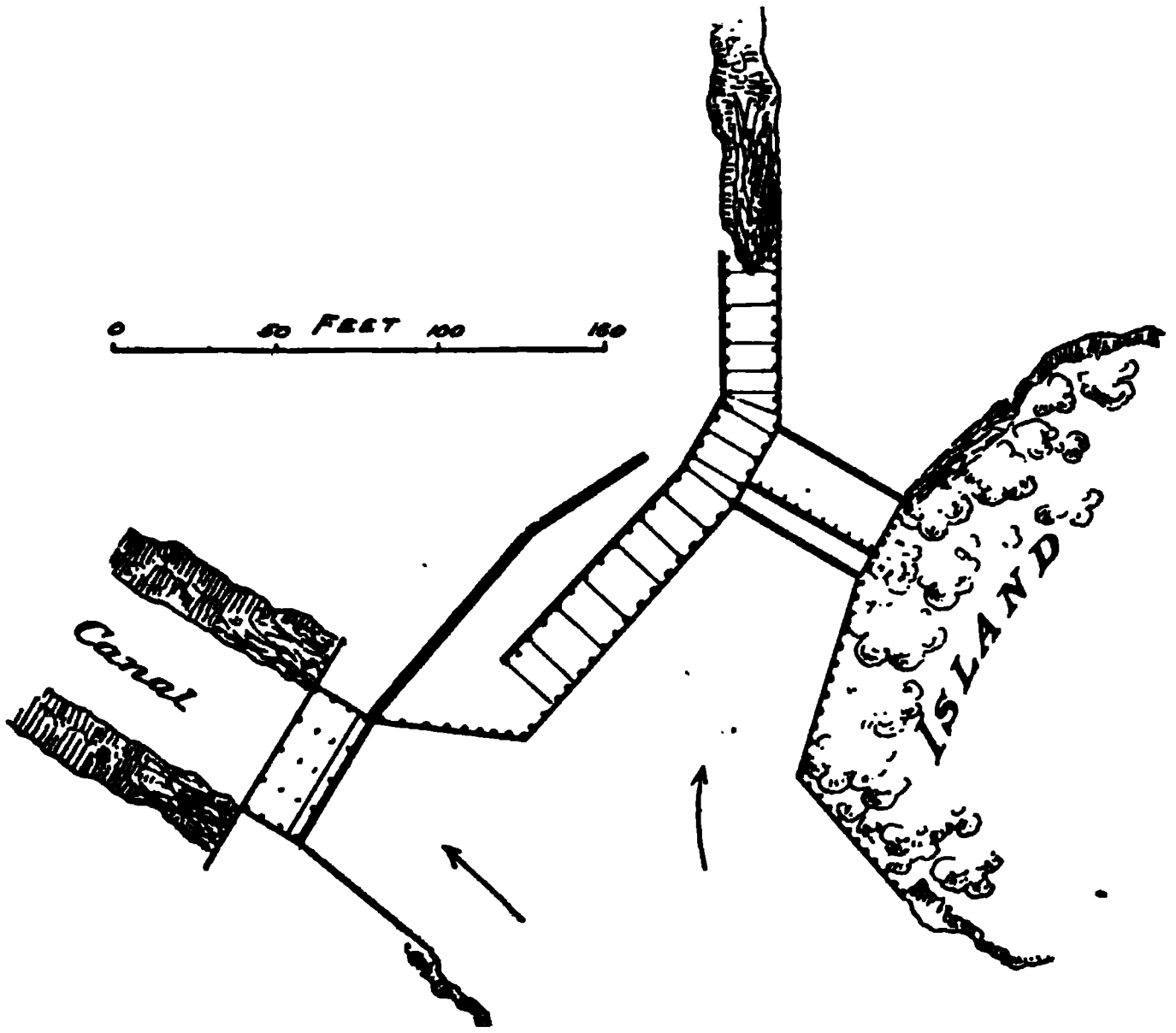


FIG. 5.—Details of head works of San Joaquin & Kings River Canal.

brush dam, as is the case with all structures of its type, must be repaired and raised annually after the spring high waters. It will thus appear that, notwithstanding the apparent simplicity of arrangement of head works, their construction and maintenance have been expensive.

The construction of this irrigation work commenced in 1871, and in that year the canal was excavated to Los Baños Creek, a distance of 38 miles. It was extended in 1877 and 1878 to Orestimba Creek, and its present terminus is but a few miles farther south. Canal construction was undertaken by a corporation which proposed not only to supply water to irrigators, but also to make a practical demonstration of the advantages of irrigation by operating a farm of its own. The land selected for farming purposes was very carefully prepared for irrigation, and the water was to be brought to the soil from irrigating

ditches in a system of cross furrows. The experiment, involving the introduction of methods that may be successful in India, where labor is abundant and cheap, proved a complete failure, and seems to have brought the entire canal project into temporary bad repute. While the affairs of the canal company were thus in a deplorable condition it was easy for the firm of Miller & Lux to acquire a controlling interest in the canal stock, and to become in time practically the sole owners of the canal. This firm had already made special contracts for water for their extensive holdings at rates below those to be established for other water takers, granted in return for right-of-way concessions, and it was soon apparent that the successful operation of the canal would depend upon them alone.

Although the general demand for water did not increase rapidly, and although comparatively few of the renters of land from Messrs. Miller &

FIG. 6.—Brush dam across San Joaquin River at head of San Joaquin & Kings River Canal.

Lux succeeded in making sufficient profit to purchase the lands farmed, the consumption of water from the canal gradually increased, the increase being notably due to its extensive use on alfalfa and pasture lands of the big cattle firm, and reached about 34,000 acres in 1882 and 1883. The area to which water is actually applied varies, according to the character of the season, within wide limits. It was only 14,000 acres in 1886 and 12,300 acres in 1890, because the preceding winters were wet. It reached 38,600 acres in 1894, and may be rated at about 27,000 acres on an average.

The system of water distributed to irrigators has not been calculated to increase the duty of water, and will account in large measure for the relatively small area actually irrigated by a work of such great extent as this canal.

It has been the practice not to limit irrigators in the amount of water

B.

STEAMBOAT CHUTE, SAN JOAQUIN RIVER, AT HEAD OF SAN JOAQUIN & KINGS RIVER CANAL.

A, As seen from below; *B*, As seen from above

to be used. They pay for water by the acre irrigated. The canal company reserves the right to charge for water wasted, when such waste can be ascertained. When there is a shortage of supply, the canal superintendent distributes water to the irrigators in proportion to the acreage for which water is required. If an insufficient quantity of water is delivered to effect the proposed irrigation, a corresponding reduction in the water bill is made. Charges for water are made by the acre, according to character of crop irrigated. The rates in force preceding 1880 were about as follows:[1]

For cereals during any part of the season from July 1 of one year to the same date the following year, $2.50 per acre.

For alfalfa, $3 per acre per year.

For market gardens, $5 per acre per year.

For wild-grass lands, 75 cents per acre per year.

For the irrigation of a second crop during the season, $1.

For the fall irrigation of lands, from July 1 to January 1, the charge for a single application is $1.50 per acre. After January 1, any number of waterings necessary to mature a crop of cereals is given for $1.

These rates have at various times been modified somewhat. The rate for alfalfa has recently been $2.50 per acre per year, and, under agreement to take water for the season, application being made before October 1, $2 per acre. No charge is made for the irrigation of small gardens of those irrigating large tracts of grain or alfalfa. The special contract made with Messrs. Miller & Lux gave them water at about one-half of the above rates.

The distribution of water from the canal to irrigators is in charge of a canal superintendent. Those requiring water must give ten days' notice and must specify the number of acres for which water is wanted, as well as the particular tract of land to be irrigated.

The soils to which water is applied from this canal are thus described by Mr. James D. Schuyler:[2]

The lands irrigated by the San Joaquin and Kings River Canal vary so greatly in character that the practice of irrigation is not uniform. From the point where irrigation first begins, near Firebaugh's, 8 miles below the head of the canal, to its terminus at Orestimba Creek, there is a gradual change in the quality, depth, and texture of the soil, from the minimum of absorbtiveness and the consequent maximum number of irrigations required to produce crops, to the maximum of absorbtiveness and the minimum of applications necessary. The soils which retain moisture longest are those which absorb most water and are consequently best adapted for irrigation. In no irrigated section of the State are the extremes in quality of soil more marked. The adobe soils do not extend the entire distance from the canal to the river, but seem to be principally limited to a strip 2 to 5 miles wide from Firebaugh's to Los Baños Creek. They are shallow—from 1 to 2 feet deep—and underlaid with yellow clay hardpan. East of this strip to the river the soil is generally of an alluvial character, highly susceptible of profitable irrigation, but not heretofore provided with facilities for irrigation, the land being devoted exclusively to grazing purposes. On either side of Los Baños Creek the soil is a

[1] Report of State Engineer, 1880, Part IV, Appendix, J. D. Schuyler.

[2] Idem, p. 166.

compact sandy loam for a mile or two in width, very fertile, and well adapted to irrigation. With the exception of 3 or 4 miles along the canal where San Luis Creek spreads out upon the plains, the soil for the remaining distance to the terminus is a light-brown argillaceous loam, with an occasional admixture of sand. It is 30 to 40 feet in depth, compact, fertile, and highly retentive of moisture.

The shallow soils referred to in this description are those at, or but slightly elevated above, the western limit of the submersible portion of the valley. The soils to the east of this strip of inferior land are within the flood limits, and those traversed by the lower sections of the canal are of the general type of the high west-side plain.

The method of irrigation generally practiced from this canal is that of flooding in contour checks of large area. The irrigation of grain lands has been found profitable, but opinions of irrigators differ as to the best time of applying water. Near the upper end of the canal the practice of applying water to the growing crop is preferred, each crop receiving two to five waterings, according to character of soil. Along its lower portion the method of wetting the ground in the fall before plowing seems to be the most satisfactory. In this case the rainfall, generally 8 to 12 inches, is relied on to mature the crop. Orchards and vineyards are irrigated by the furrow method.

The surface of the lands irrigated is remarkably smooth, and its slope toward the trough of the valley is generally 5 to 10 feet to the mile, thus adapting it admirably for irrigation. The system of check-levee building does not, however, conform with the most advanced practice. These check levees are usually made too steep to permit of their being crossed at random by farming implements. A little is thus saved in first cost, but often at considerable sacrifice in convenience of tillage.

The cost of preparing the ground with ditches and check levees is stated by Mr. Schuyler at $1.50 per acre for the large farms owned by Messrs. Miller & Lux. He gives the cost of the check levees at $12 per mile. They are built with a V scraper.

The main canal was originally constructed with a bed width of 28 feet, a depth of 4 feet, and side slopes of 2 to 1. Its gradient was fixed at 1 foot to the mile. It was soon found that these dimensions gave the water greater velocity than the light soil of the banks could stand, and to prevent erosion their slopes were reduced to 5 to 1. The disadvantage of this very flat slope manifested itself some years later, when reeds, weeds, and mosses took root in the shallow water at the edge of the water surface and gradually encroached upon the deeper water, rendering it necessary to keep men at work during the summer cutting out the rank plant growth, and making it very difficult to force a full supply of water to the lower canal sections. Among the appliances used to cut the weeds, particularly one trailing species, the most successful was a long chain dragged upstream by means of horses, generally one on each bank.

About ten years ago it was finally decided to clean out the canal thoroughly and at the same time to cut its banks as nearly vertical as

A

B.

REGULATOR IN SAN JOAQUIN & KINGS RIVER CANAL.

A, As seen from above. *B*, As seen from below.

possible. This was done with excellent success. The canal bed was made 45 feet wide, with its sides practically vertical, and the water depth was increased to 6 feet. The soil of the banks, impregnated with the mud deposits from the canal water and rendered resistant by the roots of plants which had penetrated it in all directions, showed no further tendency to erosion, and the great inshore depth of water, as well as its velocity, retarded the growth of plants.

Below Los Baños Creek the fall of the canal was made only 6 inches to the mile. This 6-inch fall practically commences 2 miles above Los Baños Creek, as for some reason the grade line of the canal bed was raised 1 foot at that point. Experience on this canal seems to justify the conclusion that for a canal of its size a slope as light as 6 inches to the mile may safely be adopted.

This canal crosses the natural drainage lines of the west-side plain at right angles. The water courses are torrential in character. They have no flow in years of scant rainfall, and in the occasional wet winters they respond quickly to the local storms, but do not maintain their flow long. Where crossed by the canal the arrangement of the crossing is extremely simple. A check weir is put into the canal just above and just below the creek channel, and an embankment, usually of gravel, is carried across the creek channel just below the canal and connected with the canal levee. When the creek rises and overtops this barrier, it is quickly cut out by the water, in whole or in part, and upon subsidence of the freshet is replaced. The flow of the creek, if there be any after the freshet, is received into the canal.

The San Joaquin & Kings River Canal was intended to be used for navigation as well as irrigation purposes, and in accordance with that idea the structures originally planned for it included arrangements for passing canal boats. They were all timber structures of unnecessarily heavy and cumbersome design and correspondingly expensive. The more modern structures on the canal are of the usual light inexpensive type so common on the canals of the West.

The distributing ditches, which usually lead off from the main canal nearly at right angles, are generally 8 to 12 feet wide on the bottom and carry water 2 to 3 feet deep. Their aggregate length is estimated at about 200 miles.

The cost of the canal and works connected therewith has been about $1,000,000, not including about $300,000 expended in maintenance and repairs. The dividends paid have probably not exceeded $250,000. At the time of this writing there is a supplementary high-line canal being constructed which will greatly increase the capacity and efficiency of this canal system. This new canal leaves the original canal about 3 miles below its head and gradually separates from it, being carried on a grade of only 6 inches to the mile. It has a bed width of about 45 feet and is generally about 1 mile distant from the main canal, with which it is connected by means of a number of short branch ditches.

Posey Slough or Dos Palos Canal.—This is a work which hardly deserves enumeration among irrigation canals, as it amounts to but little more than a control of the inflow into a natural high-water channel which breaks out of San Joaquin River about 8 miles below Firebaugh's. It was necessary in protecting west-side lands against overflow to either close the slough with an embankment connected with the west side or to put a gate into it. The latter arrangement was preferred, and the water now admitted to the slough under control is utilized in flooding considerable areas of grazing lands. The gate has a clear opening of 24 feet, divided by means of gate and bridge posts into four spaces, each of which can be closed by means of light drop timbers. The top of the gate is provided with a bridge floor, affording a crossing for the river road.

The slough continues inland for some distance as a well-defined channel through which water is led into a series of broad swales or gentle depressions. Across these depressions embankments of earth have been erected to a maximum height of 4 or 5 feet, by means of which the water is checked and made to inundate considerable areas. One embankment after another is cut for the passage of the water to the next, or the water breaks a passage of its own, and by this crude system of irrigation considerable areas of grazing land are wet during the spring rise of San Joaquin River.

It is hardly necessary to say that this method of wetting lands can be practiced only on large holdings, such as those of the Miller & Lux Company.

Temple Slough.—This is a slough of the same type as Posey Slough, though somewhat smaller. It has been similarly treated. It breaks out of the west side of the river about 3 miles below Posey Slough. Its head gate is also in use as a bridge, but the head gate is of the culvert type and is loaded on top with an earth fill. It is 16 feet wide, being divided by posts into four spaces. The bottom of the gate is at or slightly above the low-water plane of the river. The water admitted to the slough is used for irrigation in the same crude way as that of Posey Slough.

Sanjon de Santa Rita.—This is a third slough which breaks out through the west river bank, but, unlike Posey and Temple sloughs, it has a comparatively direct northwesterly course to a reunion with the main channel of San Joaquin River, about 12 miles below its head. There is no gate at its head for the control of inflowing water, but by means of temporary spur dikes or dams of sand and brush built into the main stream its period of flow is prolonged somewhat beyond what it would otherwise be. Water is diverted from the slough into a short ditch for the irrigation of several hundred acres of land at the Miller & Lux home place, the Santa Rita Ranch. The head of this ditch is about 3½ miles below the head of the slough, on its west bank. The flow of the water into the ditch, which has a width of 10 to 12 feet, is controlled by means of a light gate.

A.

B.

BLYTH CANAL.

A, Head at San Joaquin River. *B*, Nine foot cut.

Blyth Canal.—The main supply of water for the grassland irrigation on the Chowchilla Ranch—already referred to in describing the Chowchilla Canal—is obtained from the San Joaquin River through the Blyth Canal. (See Pl. III.) This is an east-side canal from San Joaquin River, the head of which is some miles below Las Juntas. The canal is cut boldly into the river bank, with a bottom width of 20 feet. It receives water from the river only at high stages. Its flow is controlled by a well-constructed regulator or head gate of the culvert type. It supports a 5-foot fill of earth, which serves as a roadway across the canal. The entrance to the culvert is divided into five 4-foot spaces by vertical posts, which afford support to vertically sliding flashboards, 3 by 12 inches, raised by means of two double hooks engaging on iron pins, to which power is applied by a winch. The canal discharges into the east-side flat valley trough, where its flow is intercepted by a series of cross levees, each extending from comparatively high ground at the river eastward across the depression. These cross levees, five or six in all, are about a mile apart and are all equipped with stop gates, for the discharge of surplus water to lower levels. The basin above the uppermost one is first filled, then water is allowed to flow through its stop gate to the second, and so on to the last, thus effecting wholesale and very economical grass-land irrigation.

East Side or Stevenson-Mitchell Canal.—This canal, as its name implies, is an east-side diversion. The head of the canal is at a point on San Joaquin River about 14 miles southwest of Merced. It has a northwesterly course from this point for a distance of 20 miles, to near Merced River, and commands a strip of land intermediate between the canal and San Joaquin River, 2 to 4 miles in width. (See Pl. IV.) The first few miles of its course are over heavy clayey soils within the limits of the river's flood plain; the rest of its course is out upon the sandy plain which skirts the southern bank of Merced River. It commands about 50,000 acres of land.

The canal was constructed in 1887 by Messrs. J. J. Stevenson and the late John Mitchell, who were the principal owners of the lands commanded. It is 42 feet wide on the bottom and has side slopes of 1 to 1 to the natural surface of the ground, generally at 4 feet above the bottom. The fall is 6 inches to the mile. The canal levees rise about 3 feet above natural ground and are set back 10 feet from the edge of the excavation. The proposed maximum water depth is 6 feet and width on water surface 74 feet. The steep sides of the canal excavation were adopted as a result of the experience on the San Joaquin and Kings River Canal—to prevent the growth of weeds and aquatic plants, which take root readily on flat slopes.

All structures on the canal are of a simple flashboard type. There is provided a regulator or head gate, and the flow of water in the canal is further controlled by means of six check weirs, locally called stop gates. The canal crosses the natural drainage of the country. At each water course thus crossed an inlet gate is put into the upper or

east-side canal levee and an outlet gate into the lower levee. These gates, 36 in all, range in width from 12 to 64 feet. All of them, as well as the check weirs in the canal, are bridged over. During winter the canal is out of service, and all of the gates are left open, to admit of the free passage of drainage waters across the line of the canal. The first cost of the canal work was about $80,000, which has been increased by subsequent expenditures, principally on the construction of branches, to about $125,000.

Water is sold from this canal by the acre irrigated, the charge being $2 per acre if application be made for water before the 1st of January, and $2.50 per acre if applied for later. This difference in the rate per acre is intended to induce irrigators to make application before it is known whether rainfall alone will prove sufficient to produce a grain crop.

The water distributed is under control of a canal superintendent. The canal company furnishes the gates for water delivery to irrigators. All lateral or branch canals are constructed by the irrigators and at their expense.

FRESNO RIVER.

HYDROGRAPHY.

Fresno River is a small torrential stream which drains the western slope of outlying spurs of the Sierra Nevada and which debouches upon the plains of San Joaquin Valley about 15 miles to the north of San Joaquin River. The river is dry in summer, but ordinarily has a considerable winter and spring flow. Its drainage basin above the point where it leaves the hills has an area of 272 square miles. Its flow usually commences in December and gradually increases till March. It ceases to flow in June, July, or August. During the rainy season it is subject to sudden rises of short duration. The maximum monthly average for the period 1878 to 1884, as approximated by the State engineer, is given as 568 second-feet for the month of March.

This stream soon after leaving the foothills proper bifurcates, sending off several lesser southerly branches, among which are Adobe and Cottonwood sloughs. A branch of the former reunites with the main stream some miles above Madera.

The bed of the river is a broad sandy depression, having comparatively high banks, near the eastern edge of San Joaquin Valley, where it is here and there flanked by small tracts of bottom land. At Madera the river banks are quite low, and a few miles farther west the freshet waters of the stream spread and are carried on toward San Joaquin River in several small channels.

CANALS AND DITCHES.

The water brought down to Madera in the flume of the Madera Lumber Company is used for irrigation at and to the west of Madera. This water is in large part a diversion from a tributary of San Joaquin River. It was necessary to make this diversion high up in the mountains and to carry the water from the one watershed across the dividing ridge into the other stream, on account of the small summer flow of Fresno River.

The lumber flume is of the ordinary V-shaped type, serving to float lumber a distance of about 35 miles, from the sawmill to Madera. The waste water from the flume flows into branches of the Madera Canal.

Madera Canal (*Fresno River Dam and Canal Company's Canal*).—This is a work of some magnitude which is interesting, in part, at least, on

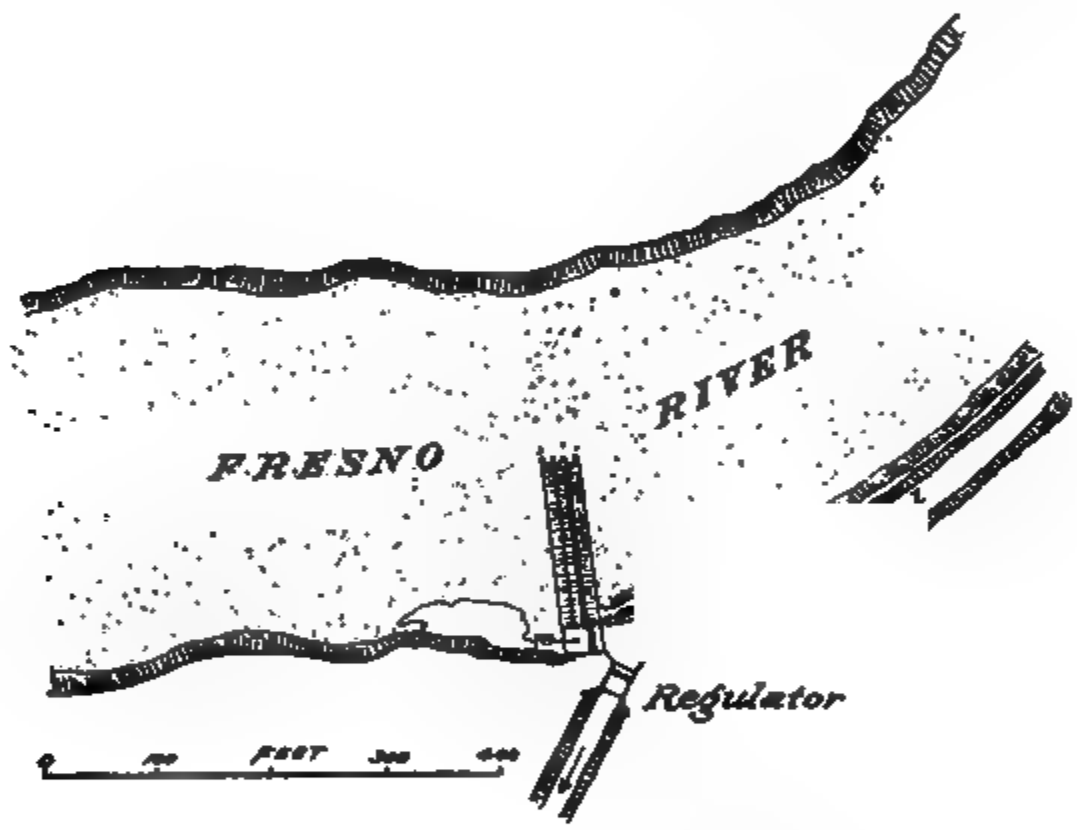


FIG. 7.—Head of Fresno River Canal.

account of the failures in which the first effort to secure water resulted. At great expense a dam was constructed across Fresno River about 2 miles above Madera, and from it a deep cut was excavated through the river bank, which there rises about 15 feet above the river bed. The dam consisted in the main of three rows of double sheet piling, reenforced by numerous ordinary piles, and a timber top work, forming a substantial sill across the stream that was intended to raise water 4 or 5 feet above the ordinary low-water plane. It was 311 feet long, and raised the water surface of the river 6 feet. It was intended also to intercept a subsurface flow supposed to exist in the sands of the river bed, but failed to develop any water from this source. A head gate and waste gate at the south end of this structure afforded control of the inflow into the canal, which was made 20 feet wide on the bottom,

with side slopes of 1 on 2. The depth of the cut through the river bank became less as distance from the river increased, and within a mile the canal was at the general surface level of the valley plain. From this point special effort was made to hold the main canal on the top of flat sand ridges, which position it was thought would afford the best possible command of the lands to be irrigated. Not only was the canal located on the highest available ground, but it was endeavored to hold the water surface in the canal and distributing ditches well above the natural surface of the ground. Material for canal banks was taken largely from the outside. After the expenditure of about $60,000 on the dam and canal it was found that breaks in the canal banks were of so frequent occurrence, and loss of water was so great, that it would be unwise to perfect or further extend the system. It was found, too, that the dam was a failure, particularly owing to the loss of water in the porous creek channel for miles above it. It was then found that by turning a portion of the river's flow into Adobe Slough, some miles farther upstream, and putting an inexpensive regulator in its head, water could be brought into the head of the canal and thence into a water course passing directly through the lands already prepared to receive it. This was done, and a few dams in the slough lower down, with regulating gates in each, completed a main canal system that has been comparatively inexpensive and has served its purpose well. About $20,000 was the first cost of this supplemental work.

It is understood that the water supply of the canal is further reenforced by the Adobe Ranch Ditch, which diverts water from the river at a point known as "Chinee Store," located in the foothills about 19 miles above Madera. This ditch is 10 feet wide on the bottom, carries water 4 feet deep, and at the Adobe Ranch, about 7 miles above Madera, is connected with, and adds in a measure to the supply of, the lower works. The canal company proposes soon to construct storage works in the mountains in order to secure a continuous flow of water for its canal system.

The lands prepared for irrigation with water from this canal have an area of about 16,000 acres. They lie in a compact body to the southward, beyond Cottonwood Slough. The surface of the lands irrigated is very smooth and has an almost imperceptible slope of 7 to 8 feet per mile toward the southwest, adapting them admirably for irrigation. The soil is a sandy loam, rather heavy in the eastern portion of the irrigated region, and very sandy near its western limit. The heavier soils are underlain by a shaly hardpan a few feet below the surface. This is deeper below the surface of the sands or is entirely wanting.

Water is ordinarily available for irrigation from some time in December to May. Occasionally there is a good flow in the canal during June. It is diverted from the slough above referred to into branch ditches, which leave the slough just above the dams that have been built into it.

The method of irrigation is that of flooding in contour checks. The check levees are almost invariably constructed on contour lines, each being 1 foot lower than the next one above. The space between levees is divided by cross levees into compartments or checks whose area varies between wide limits, reaching as high as 40 acres. The ordinary check has an area of about 4 to 12 acres.

A good head of water for irrigation in this section is from 20 to 25 second-feet, but irrigators are frequently compelled to be content with only 10 to 15 second-feet. Irrigation is always commenced on the highest ground; the upper check is filled, and when full, the water is turned into the next lower check, while at the same time the surplus water of the upper check is also turned into the second check through a cut or gate in the contour levee between the two checks. Irrigation progresses night and day, and two men are constantly on duty for each irrigating head of water.

Both alfalfa and grain are generally irrigated but once each season. Grain as a rule is irrigated only when long-continued drought makes irrigation necessary to save the crop. Alfalfa receives more than one irrigation when water is available long enough.

The main canal of this system was until February of this year (1897) owned by a company or association of farmers which made no agreements for the delivery of water to irrigators for longer periods than one season. The distribution of water from the canal was in charge of a superintendent, to whom application for water had to be made before the irrigating season commenced. To these parties, who were required to specify the acreage which they purposed to irrigate and the time when water was required, the water was apportioned. When there was more water in the canal than was required by them, this was available for those parties who neglected to put in application for water before the date fixed as the commencement of the irrigating season. All parties applying for water were required to pay for it whether they used it or not. If water was insufficient to meet the demands of all applicants, it was apportioned by the superintendent according to his judgment, and was paid for by the acre of land actually irrigated. The charge for water was originally $1 per acre for grain and $2 for alfalfa. Subsequently the rate was raised to $1.50 for grain, and since 1885 it has been made $2, which is the charge per acre regardless of the nature of the crop. This rate remained the same no matter how often water was applied.

Of the 16,000 acres of land prepared for irrigation, it is reported that as much as 12,000 acres have been irrigated in one season. Ordinarily, however, the area irrigated is 5,000 to 6,000 acres.

The cost of land preparation for irrigation, covering the construction of small irrigating ditches and check levees, is estimated at $2 per acre, and the cost of each application of water at about 25 cents per acre.

The canal property has recently passed into the hands of a new corporation and will be managed on lines similar to those of the Fresno Canal from Kings River, except that in addition to selling water to lands covered by water rights water will also be furnished at an increased annual rate to lands not so covered. The new company is known as the "Madera Canal and Irrigating Company." It is capitalized at $400,000, in shares of $10 each.

The water rights are at present sold at $5 per acre. The annual water rate to be paid for each acre covered by the right is $1. The canal company places the gate in the canal bank for the delivery of the water; it reserves the right to convert the irrigator's private ditch into a branch ditch under the company's control, provided such use shall not interfere with the delivery of water to the owner of the water right; it makes the water right an appurtenance of the land on which it is located; it reserves the right to shut off water for repairs, and does not hold itself responsible for deficiency of water caused by drought, insufficient water in river, hostile diversion or obstruction, forcible entry, or temporary damage by flood or other accidents, but agrees to use at all times due diligence in restoring and protecting the flow of water in the canals. The canal company also reserves the right to sell 250 water rights of 1 second-foot of water each (1 second-foot to each 160 acres), and it is to be understood that each water right sold shall, whenever the canals flow less than 250 second-feet, represent the two hundred and fiftieth part of the available supply. The purchaser of the water right makes the water rights a lien upon the land covered; he agrees not to use water wastefully, and he grants to the canal company the right of way for canals and ditches over all land owned by him and located in the same township as the specific tract covered by the so-called water right.

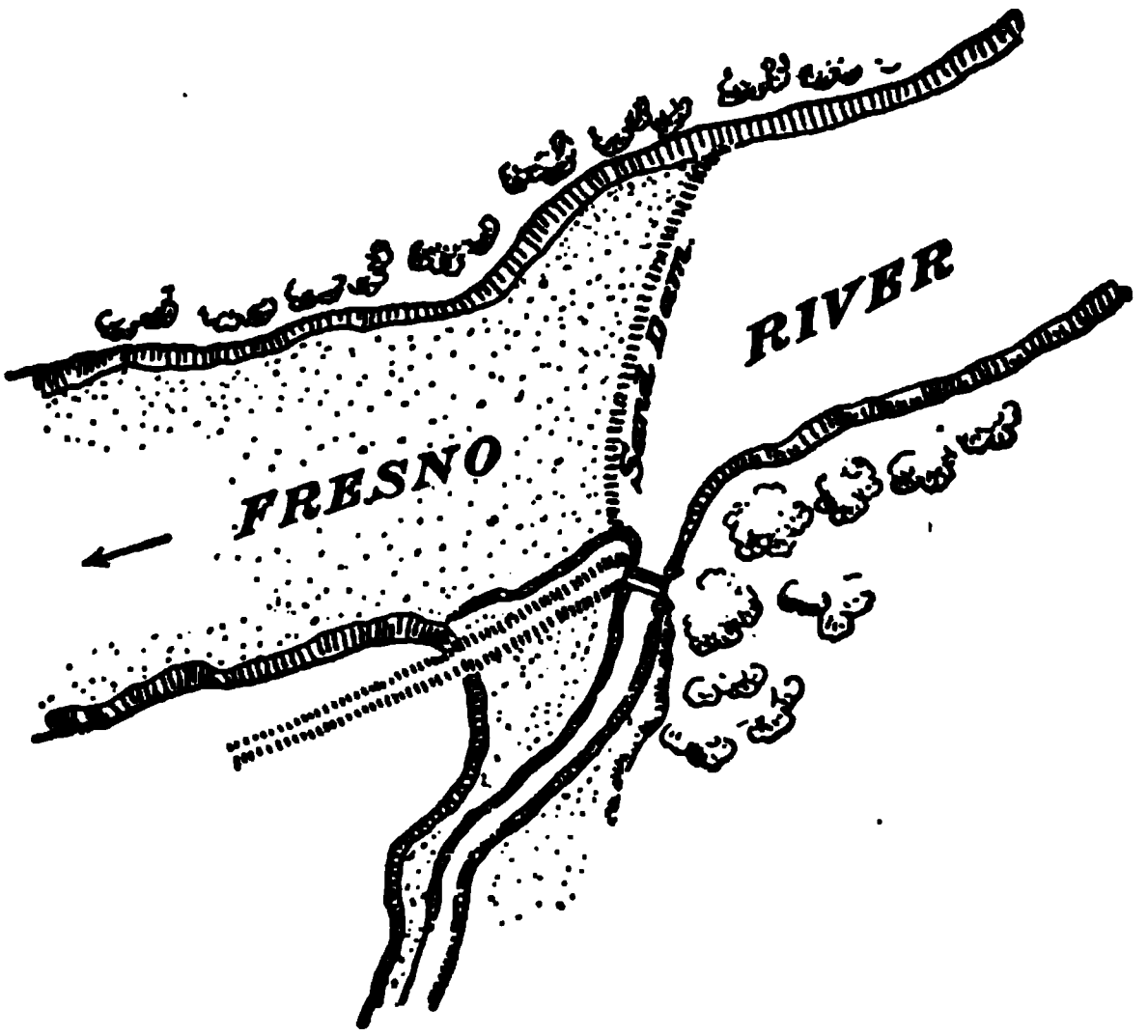


FIG. 8.—Head of Adobe Slough.

Water is delivered for $2 per acre per year to parties whose lands are not covered with water rights. The charge for grain land is $1 per acre for one wetting. The charge for garden irrigation is $5 per acre per year.

Adobe Ranch Ditch.—About 12 miles above Madera, on Fresno River, between low outlying foothills, lies the Adobe Ranch, on which between 300 and 400 acres of bottom lands are cultivated in alfalfa. Water for use on this land was made available by means of a small ditch constructed about fifteen years ago, the head of which is about 7 miles farther upstream, on the south side of the river. The water of this ditch was originally delivered into a small reservoir lying between low hills on the south side of Fresno River close by the tract to be irrigated, and water was drawn from the reservoir as required. The method of irrigation is by flooding in checks, each several acres in area. The cost of applying water is given at 65 cents per acre per irrigation.

The ditch is now said to be a feeder of the Madera Canal and is reported to have a bed width of 10 feet and to carry water 4 feet deep.

CHOWCHILLA RIVER.

HYDROGRAPHY.

The same description given for Fresno River will answer for the Chowchilla, except that its bank lands are even lower and the separation of its water into several channels soon after its debouchment on the valley plain is still more pronounced. The river's drainage basin is 268 square miles. Its flow and period of flow are about the same as noted for Fresno River.

Two channels break out from the south side of the river near the eastern margin of the valley plain. These are Berenda and Ash sloughs, both of which have a very direct southwesterly course, being respectively 4 and 2 miles from the main stream at Minturn. All of these channels across the east-side plain of San Joaquin Valley have shallow beds of sand and banks rather low, but still somewhat higher than the general surface of the plain. Their flow spreads over large areas near San Joaquin River, and there is no pronounced junction of Chowchilla River with the main drainage way of the valley.

CANALS.

Kohler, West & Minturn canal system.—The use of water from Chowchilla River for irrigation has been confined to several thousand acres of land at and near Minturn. (See map, Pl. IV.) The main river channel has been converted into a supply canal by the construction of several dams. The uppermost of these dams is just below the head of Ash Slough. It is in the nature of an earth or sand embankment carried across the river channel and equipped with a large regulating gate in its center. The gate is of the ordinary flashboard type, with a light bridge over its top. It is protected against undermining by sheet piling, and the water required for irrigation below is allowed to pass through it. Any excess flow of the river is turned down Ash and Berenda sloughs. About a mile north of Minturn and about 10 miles below the dam just referred to, a second dam of similar character is

maintained. This structure converts a section of the river into a reservoir which overflows through a gate in the dam to the lower portion of the river, and through gates in river-bank levees sends water toward. the north and south.

The water diverted at this point is used principally on the vineyard lands of Messrs. Kohler, West & Minturn. Some of it is passed on to other irrigators. The irrigation ditches are small, 8 to 12 feet wide, carrying water about 2 feet deep, and terminate within a few miles of the river.

A third dam is maintained in the river about 2 miles below the second, and water is taken from above it for the irrigation of the Minturn farm.

These dams are 8 to 14 feet high, built of such material as the river bed affords, and have stood remarkably well. The success of this system of handling the water of the river, which is 200 to 300 feet

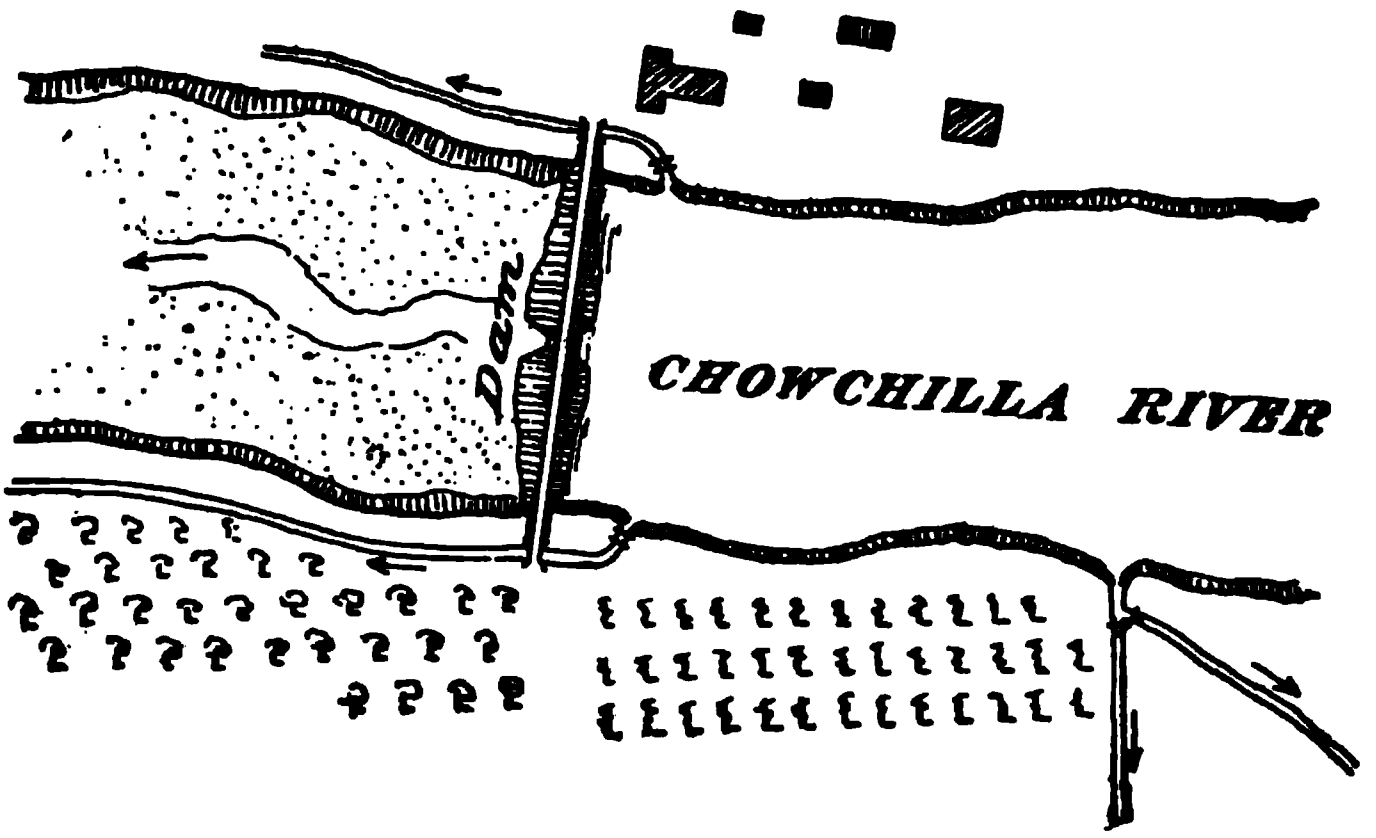


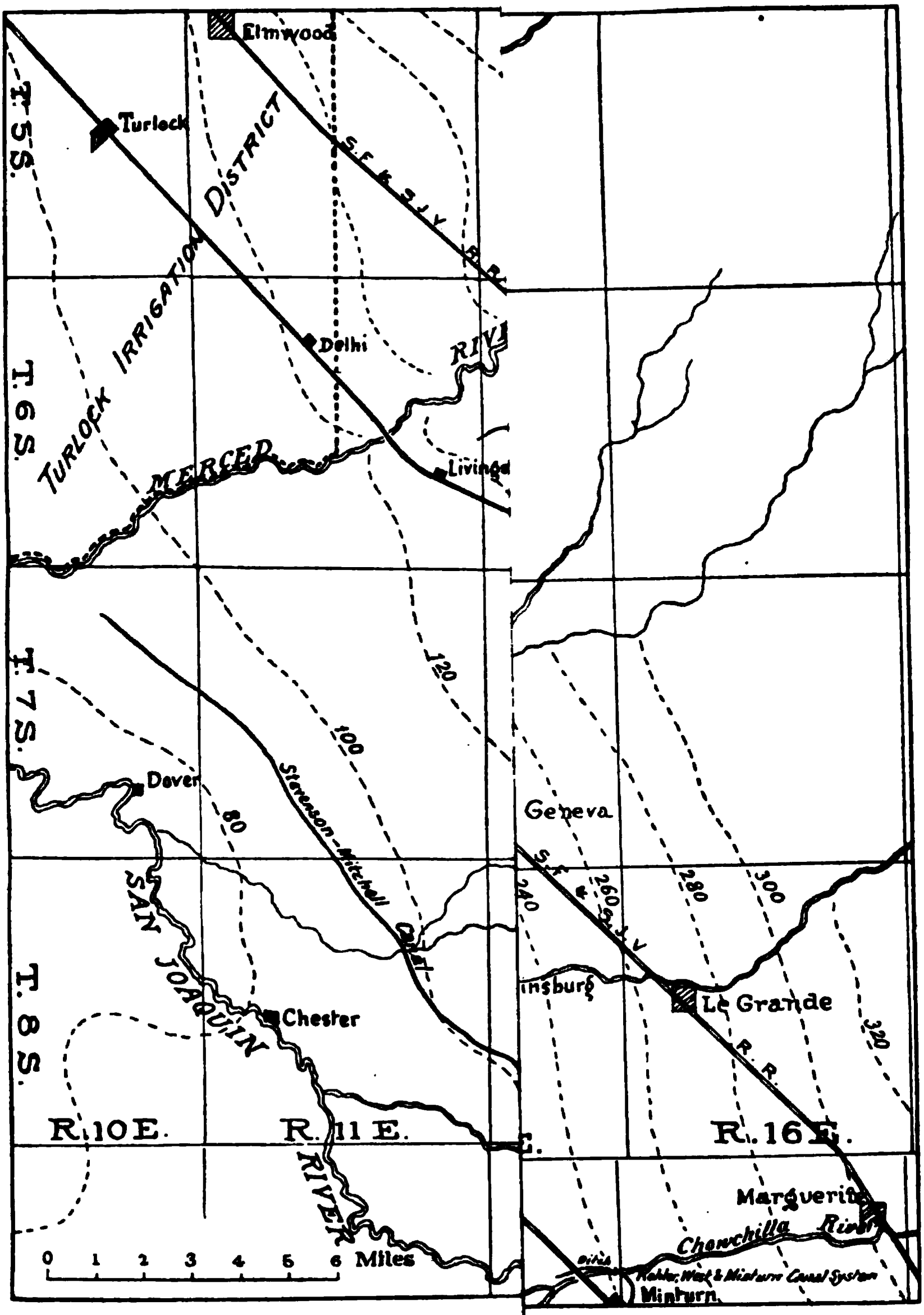
FIG. 9.—Water diversion by Kohler, West & Minturn Canal.

wide, depends, of course, upon the possibility of forcing practically the entire freshet flow into the other channels.

The method of vineyard irrigation practiced at Minturn is that of flooding in small checks, some of which have been laid out rectilinearly, while others are fitted to the contours of the ground. The soils irrigated are sandy loams, very retentive of moisture, which with water have proved very productive and well adapted to the culture of the grape.

Surplus waters—that is, water in excess of that required for the irrigation of the lands belonging to the firm owning the canal—have been held for sale. The rate which prevailed several years ago was $1.50 per acre of land actually irrigated.

Buchanan Reservoir project.—A work of considerable magnitude proposed for Chowchilla River is the construction of a reservoir of great capacity several miles above Buchanan. This work is to be carried out to secure an adequate water supply for the 30,000 acres of land of


Elmwood
Turlock
T. 5 S.
TURLOCK IRRIGATION DISTRICT
S. F. & S. J. V. R. R.
Delhi
MERCED
Livingston
T. 6 S.
120
100
80
Dover
Stevenson-Mitchell Cutoff
SAN JOAQUIN RIVER
Chester
T. 7 S.
Geneva
240
260
280
300
320
Le Grande
R. R.
T. 8 S.
R. 10 E.
R. 11 E.
R. 16 E.
Marguerite
Chowchilla River
Robbins, West & Minturn Canal System
Minturn
0 1 2 3 4 5 6 Miles

the Berenda-Chowchilla tract owned by the Sharon estate. The dam as proposed is to be built of uncoursed rubble. It is to have a height of 100 feet and will store 42,400 acre-feet of water.[1]

MERCED RIVER.

HYDROGRAPHY.

Merced River is to be classed among the principal streams which flow down the western slope of the Sierra Nevada into San Joaquin Valley. It has a perennial flow, its low-water discharge being about the same as that of Tuolumne, Stanislaus, and Mokelumne rivers, nearly 200 second-feet. The river has a high mountain and foothill watershed of 1,076 square miles. Its bed where it enters the valley is considerably depressed below the general surface of the plain. It is flanked by low bottom lands, which extend with irregular width to the base of the bluffs rising to the higher land of the main valley. The bottom lands near Snelling expand to a width of several miles, forming a secondary valley of no small importance. Westward from Livingston the main plain gradually drops to the level of the river lands, and long before a junction with San Joaquin River is effected the Merced is flanked by large areas subject to periodical inundation.

The flow of the river approximated by the State engineer for the years 1878 to 1884 indicates an average monthly rate of 1,500 second-feet for February, over 1,700 second-feet for March, 3,000 to 5,000 second-feet from April to June, 1,900 second-feet in July, 400 to 600 second-feet in August, December, and January, and a low-water flow of about 200 second-feet during the months of September, October, and November.[2]

These figures, indicating as they do a very considerable flow in the spring and early summer, show the importance of this stream as a possible source of water supply for large irrigation canals. Although the value of this stream for irrigation has long been recognized, as well as that of the other rivers of the same class—the Tuolumne, Stanislaus, and Mokelumne—the construction of irrigation works on a large scale has progressed but slowly. This is due, first, to the fact that the position of these streams, depressed as they are from 40 to 80 feet below the general surface of the east-side plain, makes a diversion of water upon the higher surface of this plain very expensive; and, secondly, to the fact that the lands commanded are sufficiently favored with natural advantages to render them available, in a measure at least, for farming without irrigation.

The only canal from Merced River which carries water out upon the east-side plain of San Joaquin Valley is the Merced or Crocker-Huffman Canal. All other irrigation works are comparatively small ditches in use for the irrigation of the limited bottom lands.

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[1] See American irrigation engineering, by H. M. Wilson: Thirteenth Ann. Rept. U. S. Geol. Survey, Part III, 1893, p. 314.

[2] Physical Data and Statistics, W. H. Hall, State engineer of California, 1886, pp. 434, 476.

CANALS AND DITCHES.

Merced or Crocker-Huffman Canal.—This work is the extension and enlargement of an older ditch known as the Farmers Canal. It has its head on the south side of Merced River, about 2 miles below Merced Falls. (See map, Pl. IV.) Skirting the base of the bluffs to the south of the bottom lands, it reaches the upland and, penetrating several foothill spurs, attains a position which commands the east-side plain of San Joaquin Valley to and beyond Bear Creek. (See Pl. VIII.)

The enterprise was conceived by the late William G. Collier, a surveyor and civil engineer, who had already had some experience in constructing irrigation ditches from Bear Creek. An organization of farmers was formed, which incorporated in 1873 under the name of the Farmers Canal Company, and work on the canal was pushed forward as rapidly as the available means would permit. Unforeseen difficulties, notably due to lack of funds occasioned by excessive cost of excavation, prevented the plans from being fully carried out as originally proposed. However, by March, 1876, the canal reached Canal Creek, and water was, through it, made available for irrigation. The length of the canal to this point was about 8 miles. For most of the way it had been cut into a hard gravelly soil, which cost to excavate about 20 cents per cubic yard, instead of 10 cents, as had been estimated. It penetrated a ridge by a tunnel 1,600 feet long, 11½ feet wide by 9 feet high, which cost about $20,000. This tunnel is in soft sandstone and firm cemented gravel, and did not require lining. The canal as constructed had a bed width of 20 feet, and was 4 feet deep. It followed, in a southwesterly direction, a grade line having a fall of 1 foot to the mile, except at the tunnel approaches and in the tunnel itself, where the fall was increased to 10 feet to the mile.

The Farmers Canal Company could not succeed in making arrangements for the extension of the canal beyond Canal Creek, and finally sold out to Messrs. Charles Crocker and C. H. Huffman in 1882. The enlargement of the canal was commenced at once. Except one change of location near the head of the canal, the original alignment of the old ditch was all too carefully adhered to. In making the enlargement to a bed width of 60 feet, the material handled, including original levees and spoil banks, was fully as great as it would have been on a new route adapted to the increased canal dimensions, and it is questionable whether a complete change of alignment for some of the canal sections would not have been advisable. The tunnel, too, was enlarged to a width of 22 feet, while it might well have served for many years without enlargement.

Near its head the new canal was made 80 feet wide on the bottom. It was planned to have a depth of 10 feet throughout. Its extension beyond Canal Creek was rapidly pushed. The creek channel was enlarged, and for about a mile became a section of the canal. From

DAM ACROSS MERCED RIVER FOR CROCKER-HUFFMAN CANAL.

REGULATOR IN CROCKER-HUFFMAN CANAL.

that point the main canal was given a more southerly course, skirting the western base of a number of foothill spurs and finally penetrating one at a point about 8 miles north of Merced, in a timber-lined tunnel 20 feet wide, 13 feet high, and 2,100 feet long, with a total fall of about 5 feet. Tunnel frames are constructed of timbers, 12 by 14 inches, 4 feet apart. Lagging and flooring are 3 inches thick, all redwood. Tunnel lining required over 1,000,000 feet of timber, and it alone is said to have cost about $30,000. It is extremely doubtful whether the reduction of a few miles in the length of the canal could justify its construction, even if it had been found to require no lining. The total cost of the tunnel was about $70,000. Work on it progressed night and day, and it was completed in about six months. (See Pl. VII.)

About 6 miles below the tunnel just described, and about 12 miles by canal from Canal Creek, the canal delivers its water into a reservoir, the primary purpose of which is to afford a reliable supply of water to the city of Merced, lying about 6 miles farther to the southwest. This reservoir has a surface area of about 600 acres. It lies between two low foothill spurs, the gap between which was closed by means of an earth dam having a crest length of 2,200 feet and a maximum height of 50 feet. The dam rests on a very firm foundation of cemented gravel, into which a wide, deep puddle trench was cut. Much of the material of which it is constructed had to be loosened by blasting. All material was wet when put into place, and was firmly trampled by horses. There was enough clay in the material used throughout the structure to make it a very compact bank.

A masonry conduit, brick laid in cement mortar, has been carried through the natural foundation under the dam, and in this the delivery pipe and the sluice pipe have been placed. (See Pl. IX.) The main canal is continued southward, or rather southeastward, from the reservoir on a continuation of the grade line entering the reservoir from the north. This arrangement cuts the canal extension out of a supply when the reservoir is not full. Water was turned into the reservoir through the completed main canal on February 1, 1888.

The diversion from the river is made at a point where Merced River leaves the base of a vertical cliff which rises to the south. The canal head gate or regulator is constructed between two rock-filled timber piers or bulkheads, of which the southernmost rests against the foot of this cliff. The regulator has a width of 80 feet, divided into a number of small spaces between vertical posts, all of which are controlled by means of vertically sliding gates. (See Pl. VI.) From this gate a timber dam, raising the water surface about 8 feet, extends, with a broad downstream sweep, across the river to a connection with the bottom land on the north side of the river. (See Pl. V.) The dam proper rests on a timber platform or sill, which, extending downstream 10 or 12 feet below the lower face of the dam, forms an apron, on which the overfalling water is received. Considerable trouble has been experienced in repairing cuts which the river has made through the bottom lands around

the north end of the dam. The cost of this entire work, including the distributing system of pipes in Merced, is given at about $1,500,000.

In April, 1888, the owners of the canal incorporated under the name of the Crocker-Huffman Land and Water Company and declared themselves ready to furnish water for irrigation. The canal company sells so-called water rights, which are very similar to those issued by the Fresno Canal and Irrigation Company. The purchaser of a right pays for it at the rate of $10 per acre. He designates the particular tract of land for which the right is purchased, and the rights acquired by the purchase become appurtenances of the land. He agrees to construct the necessary ditch or ditches for the conveyance of the water to his land, and grants to the water company the right to assume control of such branch ditches at any time and to use them for the delivery of water to other purchasers, provided that such use and control shall not interfere with the delivery of water to him. He agrees not to use the water on any land other than that described, and not to permit it to run to waste. He grants to the canal company the right of way for canals, flumes, and pipes across land belonging to him, or that may hereafter come into his possession, in the same township as that in which the specified tract is located. He also binds himself to pay a fixed sum annually, generally $1 per acre, on the first Monday of September, and in case of a violation on his part of the water-right agreement the contract, except in so far as it relates to a right-of-way grant and to the making of the water right an appurtenance of the land, may, at the option of the water company, be declared forfeited. On the other hand, the water company grants a water right in perpetuity, agreeing to furnish water at the rate of 1 second-foot for each tract of 160 acres; it agrees to construct the necessary gate in the canal bank for the delivery of the water and to use reasonable diligence in maintaining its works, reserving the right to sell water on similar terms "to the full capacity of its canal," which is not otherwise defined. When the supply is insufficient to afford to each taker the full amount of water to which he is entitled, a delivery of a proportional amount shall fully satisfy the covenants entered into. All of the work done in connection with this irrigation system was carried out on a broad scale. The entire system is of magnificent proportions, and can not fail to become in time one of the most reliable and important in San Joaquin Valley.

It is unfortunate that the first projects for the establishment of colonies dependent on this canal for water resulted disastrously, because the district which the canal commands is, as a whole, well adapted for irrigation, and a successful colony enterprise would have gone far toward demonstrating possibilities of development with irrigation.

Among the first lands sold in small subdivisions was a tract of about 4,000 acres, located in the bad-land strip on the base of the hills about

TUNNEL NO. 2 ON CROCKER-HUFFMAN CANAL.

CROCKER-HUFFMAN CANAL NEAR HEAD, LOOKING DOWN.

6 miles north of Merced. These lands were sold to a colony of Hollanders, who failed to achieve the results anticipated. They experienced great difficulty in preparing and cultivating the shallow, coarse, gravelly, hogwallow soil, which, unlike the black soil of the Bear Creek country nearer Merced, or the sandy loams of Atwater and Livingston, had before canal construction been considered worthless, except for grazing purposes. The efforts of the colonists proved unavailing, and after a time it was realized that the cultivation of the selected tract in small areas of fruits, truck gardens, and the like, could not be made profitable, and the colony project was abandoned.

This unsatisfactory experience, together with the general business depression of the last few years, will account in large measure for the comparatively small demand that has been made for water from the Merced Canal. The area actually irrigated in a season has probably not exceeded 12,000 acres.

MERCED RIVER BOTTOM CANALS.

The bottom lands flanking Merced River, extending downstream from Merced Falls to near Livingston, are in large part irrigated by a number of small ditches, chiefly interesting from the fact that some of them are among the oldest irrigation works in San Joaquin Valley.

Merced Falls mills.—Power is supplied to a flour mill and to a woolen mill at Merced Falls by water from Merced River, which there crosses a ledge of slate. The natural fall of the rapids at that point is increased by means of a light dam, about 800 feet long, which follows the crest line of the slate reef from bank to bank. This dam is of the lightest possible type, being constructed of a series of inclined timbers, usually 4 by 6 inches, loosely resting upon the rock and supported from below by means of shores, irregularly spaced according to facility of support afforded by the uneven surface of the rock. The spaces between timbers are closed with 1-inch boards. The maximum height of the structure is about 8 feet. Power has been developed at the falls since about 1856.

Merced Falls Ditch.—The water from this ditch is taken from the north side of Merced River above the dam at Merced Falls, but the rights of this ditch are subject to the prior rights of the mills. The ditch was constructed in 1857 and has been in use to some extent ever since. It is about 2 miles long, 4½ feet wide on the bottom, 1½ feet deep, and has a fall of about 2 feet to the mile. The area irrigated by it is 300 to 400 acres. Like all the ditches in Merced Bottoms, it is a private ditch, supplying water only to lands of its owners.

Murray Mill Ditch.—This is another small north-side ditch, which has its head about 1½ miles below Merced Falls. A low dam of cobbles and brush is annually thrown across the river to force water into the ditch, which is about 3 miles long. The ditch has a width of about 10 feet, carrying water 1 to 1½ feet deep, and supplies water to about 100 acres

of land. It also furnishes power for a small gristmill located about a mile below its head. The ditch was constructed about 1858, in which year rights of way for it were secured, but it fell into disuse and was reconstructed or enlarged in 1862. The dimensions originally intended, and which were probably given the earlier ditch, were described as follows: 5 feet wide on bottom, 7 feet on top, and deep enough to carry 2 feet of water.

Snelling Ditch.—The Snelling Ditch was constructed in 1860, or about that time, for the irrigation of lands near Snelling. A company was formed composed of interested landowners, and ownership in the ditch was represented by shares of stock. The head of the ditch is on the north side of the river, about 2 miles above Snelling, which was at the time of the ditch construction a prosperous town and the first county seat of Merced County. A temporary dam of cobbles and brush is annually constructed at the head of the ditch. The ditch is about 4 miles long, 6 feet wide on the bottom, and carries water from 1 to 2 feet in depth on a grade of about 2 feet to the mile. The irrigation is confined principally to orchards, vegetables, and alfalfa, Chinese being the renters of most of the land irrigated.

Montgomery & Anderson Ditch.—This is another old-time ditch of small capacity. Its head is on the north side of Merced River, at the ford, about a mile above Snelling. It is about 1½ miles long, and supplies water to a few acres of alfalfa, orchard, and gardens near Snelling. Its bed width is only about 4 feet, and the depth of water carried is about 1 foot.

Ingalsbe Slough.—This is a natural high-water channel, which breaks out through the north bank of Merced River just above Snelling. It has a westerly course along or near the northern margin of the bottom lands for about 8 miles, and supplies water to several small ditches, notably the Ruddle ditches, besides wetting considerable areas by infiltration of water from the slough into the porous subsoils. A barrier has been erected across the head of the slough, and in this a regulating gate is maintained.

Scott Ditch.—The head of this ditch is on the north side of Merced River, about a mile below Snelling. It was constructed in 1857, has a bottom width of about 3 feet, and is about 2 miles long.

Dean Ditch.—This is still another small ditch, on the north side of the river. It takes water about 1½ miles below Snelling, is about 3 miles long, 5 feet wide on the bottom, and 1 to 2 feet deep. Some of its water is dropped into Hopeton Slough.

Old River.—This is an old channel about 3 miles below Snelling. During the freshets of 1861–62 Merced River cut a new channel near the southern margin of its bottom lands, abandoning about 3 to 4 miles of its old channel. This is now known as Old River, and a cut has been made at its head to increase its flow and to make it serve as a source of supply for the irrigation of a number of farms. A little over

INLET TO MERCED RESERVOIR, CROCKER-HUFFMAN CANAL.

2 miles below its head water is diverted from it into the Sillman & Ruddle Ditch, in which it is carried westerly about 3 miles. This ditch has a bed width of 7 feet, and carries water 1 to 2 feet deep. It has a fall of about 7 feet to the mile. Half a mile below the head of the Sillman & Ruddle Ditch is the Means or Montgomery Ditch, which irrigates a few acres of land lying between Old River and the present channel of Merced River.

Feldhaus & Reed Ditch.—This is a south-side ditch, having its head about 2 miles above Snelling, just below the head of the Snelling Ditch. It is between 2 and 3 miles long, and supplies water for the irrigation of several hundred acres of bottom land on the south side of the river, opposite Snelling. The ditch penetrates the point of a hill in a tunnel about 400 feet long, 3 feet wide, and 5½ feet high. The ditch was constructed in 1865, and was made 6 feet wide on the bottom, 1½ feet deep, and has a fall of nearly 5 feet to the mile. All parties interested in this ditch contributed toward the construction of that part of it located above the point where it leaves the land of each, in proportion to individual interests. The expense of maintenance is apportioned in the same way. No water is sold.

Hamlin or Millrace Ditch.—Water is diverted from the south side of Merced River into this ditch about a mile above Snelling. It has a course parallel with the lower portion of the Feldhaus & Reed Ditch, but extends beyond it, being about 2½ miles long. It is 7 feet wide on the bottom, carries nearly 2 feet of water, and has a fall of between 4 and 5 feet to the mile. The ditch was constructed for irrigation purposes. Its owners were subsequently interested in the erection of the Merced flour mill, and the ditch became a part of the mill property. Some concessions to the use of its water were made for right-of-way privileges. Irrigators use the waters of the ditch on Sundays, at night, and at other times when the mill is not running. Several hundred acres of alfalfa and orchard are dependent on it for a water supply.

Griffith & Shaver Ditch.—This is a ditch on the south side of Merced River, about 10 miles by river below Snelling. It is a small ditch, about 2½ miles long and 3 to 4 feet wide. It has been poorly maintained, and has been out of service at various times.

Other small ditches, besides those enumerated, have been in service in Merced Bottoms; but it is impossible to obtain full and accurate data relating to them or to many of those mentioned, for the reason that official records disclose nothing more, as a rule, than a claim to water antedating ditch construction or possibly a right-of-way grant, and all other facts relating to the history of irrigation must be compiled from the recollections of the oldest inhabitants.

METHODS OF WATER DIVERSION AND USE.

Except in the case of the Crocker-Huffman Canal and the Merced Falls Ditch, the diversion of water from Merced River is accomplished by means of temporary dams constructed of brush and cobbles. These

are, as a rule, renewed after the high waters of each season, though occasionally they serve through several years. The inflow of water into the ditches is generally regulated by means of primitive wooden gates. In some cases overfalls or escape ways near the heads of the ditches reduce the amount of water to ditch capacity.

Before the flood year of 1861–62 Merced River had a well-defined channel, with high banks, from Merced Falls to near Livingston. The high water of that year, however, washed away large tracts of the alluvial soil of the bottoms, leaving in their stead great cobble beds; it caused a general silting up and widening of the river channel and a consequent rise of the plane of the water surface, as well in the river as in the adjacent soils of the bottom lands. Since that time it has been an easy matter to accomplish a diversion of water for use on the bottom lands of the river.

On these lands the crops generally irrigated are fruits, grapes, hops, alfalfa, and vegetables. Many of the orchards are not well cared for, being leased to Chinese from year to year. Alfalfa is irrigated by flooding in small checks; orchards and vineyards in furrows. Irrigations are frequent. They commence with the cessation of rains and continue at intervals of three or four weeks for orchards, vineyards, etc., until their product is matured. Each new growth of alfalfa receives at least one wetting. Ground in which grain is to be planted is sometimes wet before plowing. To some extent lands are moistened by the rise of water in the porous subsoils, caused by infiltration from the irrigation ditches and water courses. The ditches are owned by the landowners, and the cost of water from each is a proportional part of the cost of maintaining the works. Water is generally used in turn by those irrigators dependent upon the same ditch for their water.

TUOLUMNE RIVER.

HYDROGRAPHY.

The description written for Merced River applies also to this stream. Its mountain drainage basin is, however, somewhat larger, covering 1,635 square miles, and the extent of its bottom lands is considerably less than those of Merced River.

Its low-water flow at the mouth of its canyon above Lagrange ordinarily covers the period August to December. The winter rise of the stream, due to rainfall in the foothills and low mountain spurs within its watershed area, is immediately followed by the spring rise, due to the melting of snow in the higher mountains. The flow of the stream gradually increases till May or June, and falls rapidly in the latter part of June and in July. The maximum average monthly flow, based upon the approximations of the State engineer department, for the six years 1878 to 1884, has been noted at 4,500 second-feet for May.[1]

[1] Physical Data and Statistics, W. H. Hall, State engineer of California, 1886, pp. 431, 476.

The extensive freshet flow, which occurs in winter, when warm rains fall upon snow, may reach 120,000 second-feet.

There has been but little use made of water from this stream for irrigation, but works on a large scale have been commenced which are quite in keeping with its importance as a source of supply.

Two gaging stations have been maintained on this river by the United States Geological Survey, one at Lagrange, near where the river issues from the foothills, and the other at Modesto, farther down the valley.[1] Gage readings at the lower station have been maintained by the Southern Pacific Company for a number of years, and an attempt was made to rate the station, but owing to its proximity to San Joaquin River, whose back flow in times of high water affected the height at Modesto, the work was not so satisfactory as it might be.

For this reason the other station at Lagrange was established August 30, 1895. Its location is at the highway bridge in the town. The following facts in regard to the discharge of the river are brought out:

At Modesto:

1895. Maximum discharge, February, 19,650 second-feet; minimum, October, 120 second-feet; average for the year, 3,719 second-feet.

1896. Maximum discharge, April, 14,873 second-feet; minimum, October, 180 second-feet; average for the year, 2,927 second-feet.

Estimated monthly discharge of Tuolumne River at Modesto, California.

[Drainage area, 1,501 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth in inches.	Second-feet per square mile.
1895.						
January	16,130	1,398	4,828	296,900	3.700	3.220
February	19,650	1,322	3,915	217,430	2.720	2.610
March	10,785	1,710	3,165	194,610	2.430	2.110
April	10,012	3,255	5,824	346,570	4.330	3.880
May	16,000	6,097	11,798	725,400	9.065	7.870
June	12,530	5,616	9,163	545,110	6.815	6.110
July	6,692	1,550	3,831	235,540	2.944	2.554
August	1,550	285	848	52,125	0.652	0.565
September	5,616	200	615	36,600	0.457	0.410
October	200	120	152	9,346	0.117	0.101
November	500	210	255	14,985	0.187	0.170
December	730	180	283	17,405	0.217	0.189
The year	19,650	120	3,719	2,692,021	33.634	2.45
1896.						
January	13,686	246	3,060	189,370	2.37	2.05
February	1,880	950	1,182	68,007	0.86	0.79
March	11,798	1,006	2,725	167,578	2.10	1.82
April	14,873	1,970	3,577	212,828	2.66	2.38
May	14,754	2,550	5,180	318,500	3.98	3.45
June	14,754	6,990	11,648	693,104	7.87	7.09
July	8,735	1,306	4,121	253,408	3.17	2.75
August	1,118	300	575	35,392	0.44	0.38
September	2,918	220	574	34,191	0.43	0.38
October	474	180	224	13,797	0.17	0.15
November	7,802	273	1,210	72,012	0.90	0.81
December	3,560	516	1,028	63,247	0.79	0.69
The year	14,873	180	2,927	2,121,434	25.74	1.90

[1] Twelfth Ann. Rept. U. S. Geol. Survey, Part II, 1891, p. 322; Bull. No. 131, 1895, p. 83; Bul. No. 140, 1896, pp. 298–304; Eighteenth Ann. Rept., Part IV, 1897, pp. 378–385; Water-Supply and Irrigation Paper No. 11, 1897, p. 90; Water-Supply and Irrigation Paper No. 16, 1898, pp. 188–189.

FIG. 10—Discharge of Tuolumne River at Modesto, California, 1895–96.

Estimated monthly discharge of Tuolumne River at Lagrange, California.

[Drainage area, 1,501 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth in inches.	Second-feet per square mile.
1895.						
September	2,182	78	263	15,635	0.196	0.175
October	299	78	134	8,231	0.103	0.089
November	129	113	113	6,696	0.084	0.075
December	1,004	129	270	16,614	0.206	0.180
[redacted]						
January	7,610	350	2,312	142,159	1.78	1.54
February	1,780	1,080	1,164	66,954	0.84	0.78
March	11,796	1,006	2,735	167,578	2.10	1.82
April	7,990	2,670	3,522	209,574	2.60	2.34
May	10,100	2,670	4,429	272,371	3.40	2.95
June	8,330	5,140	7,692	457,705	5.74	5.13
July	5,330	960	3,003	184,677	2.31	2.00
August	3,060	237	485	29,828	0.37	0.32
September	1,620	132	432	25,742	0.32	0.29
October	350	75	19	7,366	[redacted]	0.08
November	5,710	237	1,135	67,543	0.83	0.75
December	3,620	670	1,083	66,603	0.83	0.72
The year	11,796	75	2,342	1,696,100	31.21	1.56

Estimated monthly discharge of Tuolumne River at Lagrange, California—Continued.

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth in inches.	Second-feet per square mile.
1897.						
January	3,930	690	1,231	75,692	0.94	0.82
February	13,200	1,840	5,173	287,238	3.58	3.45
March	10,800	2,500	4,032	247,920	3.10	2.69
April	13,500	3,280	7,735	460,263	5.75	5.15
May	14,700	9,600	11,923	732,121	9.15	7.94
June	9,300	2,500	5,673	337,566	4.22	3.78
July	4,840	490	2,181	134,105	1.67	1.45
August	570	76	237	14,573	0.18	0.16
September	140	28	86	5,117	0.07	0.06
October	750	76	222	13,650	0.17	0.15
November	3,540	260	768	45,699	0.57	0.51
December	4,060	570	1,104	67,883	0.85	0.74
The year	14,700	28	3,364	3,422,827	36.26	2.24

FIG. 11.—Discharge of Tuolumne River at Lagrange, California, 1896-97.

At Lagrange:

1896. Maximum discharge, March, 11,798 second-feet; minimum, October, 75 second-feet; average for the year, 2,342 second-feet.

1897. Maximum discharge, May 25, 14,700 second-feet; minimum, September 21, 28 second-feet; average for the year, 3,364 second-feet.

CANALS AND DITCHES.

Lagrange Ditch.—In 1871 this ditch was constructed by the Lagrange Ditch and Hydraulic Mining Company, from the upper end of Indian Bar to French Hill, at Lagrange, for mining purposes, and has been in constant use, supplying water to the gravel mines near Lagrange and to those at Patricksville, about 4 miles southwest from Lagrange. Very

little of its water has been used for any other purpose. The ditch may ultimately, however, come into service as an irrigation ditch as the demand for water for hydraulic mining decreases. The ditch is carried under the gravel deposit of Indian Bar in a box culvert; thence follows the south side canyon wall for 14 miles, being always within one-half mile of the river, and reaching the vicinity of Lagrange at an elevation of 250 to 300 feet above the water surface of the river. There are many and long flumes in use where the canyon walls are too steep and rocky to permit of open-ditch construction. The ditch has an average bottom width of about 6 feet and carries water 3 to 3½ feet deep. Its grade is 7 to 8 feet to the mile and its capacity 50 to 60 second-feet. The cost of this ditch was about $300,000. The total expenditure on the ditch property is, however, reported to have been $800,000. The annual cost of repair and maintenance is $3,000 to $4,000. The ditch drops its water into the Patricksville Reservoir about 3 miles south of Lagrange. The reservoir is formed by means of two earth dams. It has a surface area of 132 acres and a capacity of about 57,500,000 cubic feet, or 1,320 acre-feet, its average depth being about 10 feet.

Wheaton Ditch.—This ditch has gone out of service. It was a small ditch on the south side of the river, having its head at the Wheaton Dam, which was maintained in the mouth of the Tuolumne River Can yon, about 1½ miles above Lagrange, until replaced in 1891–1893 by the massive masonry structure of the Turlock and Modesto irrigation districts. Several water companies were early interested in diverting water for mining purposes from the river at or near the Wheaton Dam site, just above French Bar. Of these, the Franklin Water Company was incorporated in 1854. It and the French Bar Mining Company both sold out to the Stanislaus County Water Company in 1855. The purpose of the new company was to supply water to Lagrange and vicinity by means of ditches on each side of the river. Water was diverted from the river on the south side at a point about 500 feet above the falls or rapids, the latter being the point subsequently selected as the site for the dam. This water company sold out to the Tuolumne Water Company in 1871. The latter company at once constructed a dam, a substantial cribwork structure of sawed lumber. Its height ranged from 16 to 30 feet. Its lower face was nearly vertical. Its upstream face was covered with a timber skin, which was renewed but once during the entire life of the structure. The upstream face was but little flatter than 1 to 1. The crest length of the dam, not including the overfall wall forming the outer ditch bank at its head, was 125 feet. About 250,000 feet of lumber were used in its construction. It is reported to have cost about $24,000. Several years after the construction of this dam the entire property of the water company was sold to Mr. M. A. Wheaton, one of the stockholders, and a small ditch about 2 miles long was kept in service. Its duty gradually dwindled to the irrigation of a few acres of orchard and vegetable land (not exceeding 50 acres) in the river bottoms just below Lagrange.

B

LAGRANGE DAM DURING CONSTRUCTION

A, As seen from front, *B*, Abutment.

Lagrange Dam.—The structure which replaced the Wheaton Dam is generally known as the Lagrange Dam. It was built by the Turlock and Modesto irrigation districts. It is noteworthy as the highest overfall dam ever built on a large river. For the irrigation of the Turlock irrigation district, on the south side of Tuolumne River, which was organized in 1887, it was necessary to construct a high-line canal. A high dam at or near the Wheaton Dam site was decided upon. After long deliberation the Modesto irrigation district, on the north side of the river, determined to join in the construction of the dam, as it appeared desirable to have joint control of the diverting works with the other district and because it afforded the best command of canal routes westward to the district lands. (See Pls. X and XI and fig. 12.)

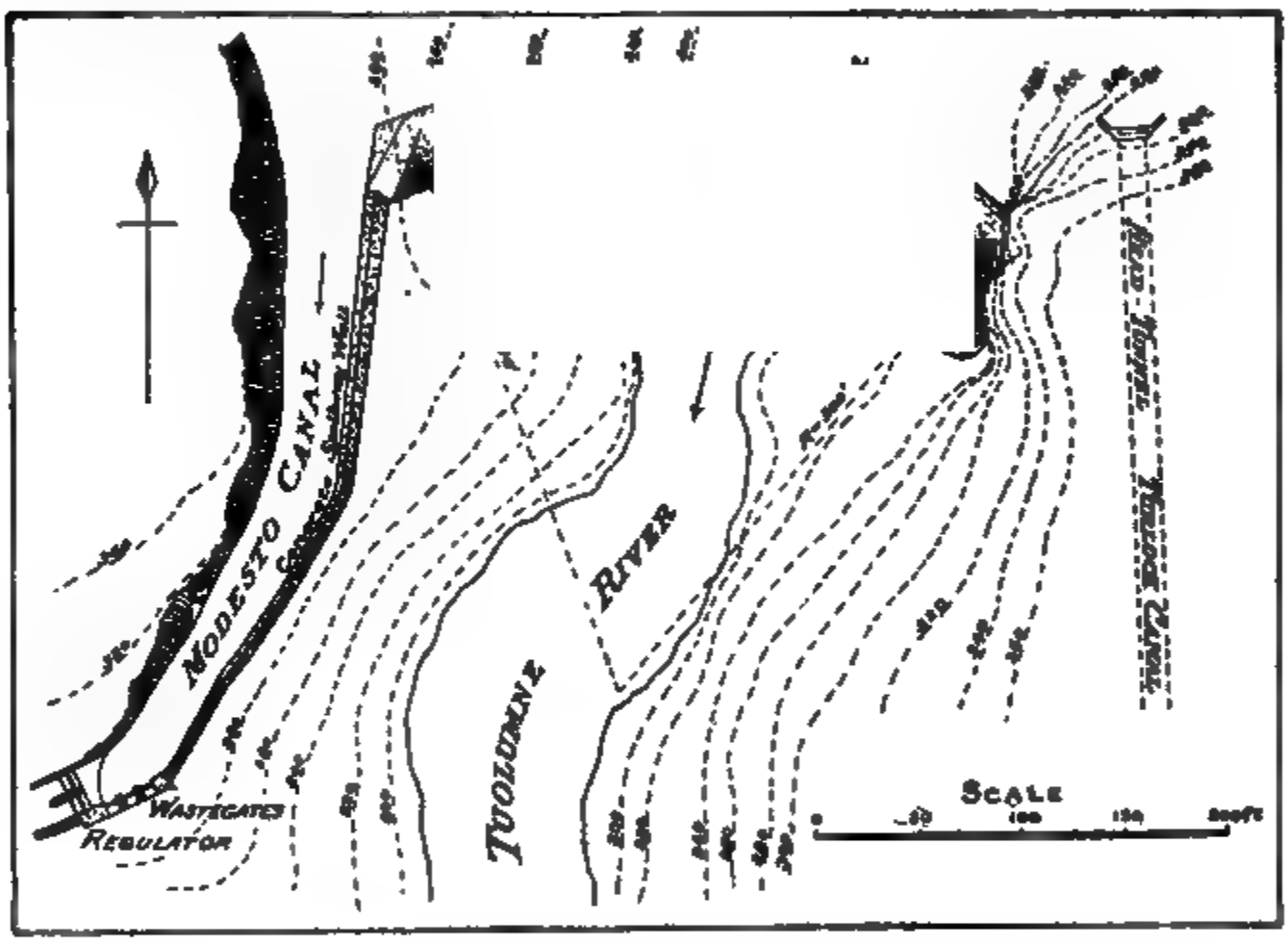

FIG. 12.—Plan of Lagrange Dam.

The engineers of the two districts were required to prepare plans for the structure, from which those submitted by Mr. Luther Wagoner were adopted; but as Mr. Wagoner soon afterwards resigned his position as engineer for the Modesto district, Mr. E. H. Barton, the Turlock district engineer, was placed in charge of construction. The dam from lowest point of its foundation surface to its crest line has a height of 125 feet. It raises the surface of the river 100 feet. It is arched upstream, its upstream face being curved to a radius of 301 feet. Its crest length from the retaining wall built for the outside bank of the Modesto canal to the cliff on the south side of the river is 310 feet. The upstream face of the dam is vertical from its top downward for 70 feet, thence to the foundation surface it has a batter of 1 in 20. The

top edges of the dam are rounded off toward the upstream face on a radius of 3 feet; toward the inclined downstream face on a radius of 17½ feet. The level portion of the top has a width of 6 feet. At 6 feet below its crest line the dam is 24.13 feet thick; at 69 feet below its top it is 52 feet thick; at 89 feet it is 66.25 feet; and at 97 feet, the top of the foundation masonry, it is 84 feet thick. The extreme bottom width at the highest point of the dam is 90 feet. The downstream face has a pitch of 1 on ½ (about 25°) down to 70 feet below the crest height of the structure, where a compound curve 64 and 23 feet radii commences, which carries the face to its intersection with the downstream face of the foundation masonry, about 3 feet above low water.

FIG. 13.—Section of Lagrange Dam.

From this line down to bed rock the masonry has a batter of 1 in 7. The dam thus affords a smooth support for the overfalling waters, which shoot off from the almost horizontal surface at the termination of the downstream face with great force against the river below. The original design contemplated the use of a second or subsidiary dam below the first, to create a pool of dead water, or water cushion, against which the force of the overfalling stream might be expended, but this has not been carried out. As the low-water width of the river—or rather its width at the height of top of the foundation—is only 80 feet, to be compared with 310, the crest length of the dam, it is apparent that during high stages of the river there must be a considerable crowding of the water from both sides toward the center of

4.

A.

B.

LAGRANGE DAM.

A, Nearing completion; *B*, At time of high water.

the stream. What effect this will have upon the solid rock walls of the canyon is not yet known; but if these show any tendency to break away on crevice and cleavage lines recourse will be had to a reenforcement with cement mortar and concrete. The dam is constructed throughout of uncoursed rubble laid in cement concrete. The cement used in the structure was furnished by the irrigation districts. The work of stripping and cleaning the foundation and putting masonry in place was all covered by the price of $10.39 per cubic yard of masonry, at which construction was contracted for. The amount of masonry in the dam is about 39,500 cubic yards. Nearly 30,000 barrels of Portland cement were used in its construction. The total cost of the dam, not including canal head works, was about $550,000. This great cost of work executed under comparatively favorable conditions must be ascribed largely to the lack of active competition among bidders for the work. There was doubt concerning the ability of the two districts to meet their obligations in coin at the time of the letting, because bonds were not selling readily at the prescribed limit of 90 per cent, and the contractors were compelled to make arangements to receive at least a portion of their pay in district bonds. During construction of the foundation masonry in 1891 the river was carried past the work in a flume. Two openings or culverts were left through the masonry at the elevation of low water and one about 10 feet above low water. These were 4 feet wide and 6 feet high, and easily passed the low-water flow of the river in the following seasons. The two lower ones were closed when the masonry had reached sufficient heigth to force the full low-water flow through the upper culvert. The upper culvert remained open long after the completion of the dam. It was closed in 1896. Water went over the top of the finished dam for the first time on the morning of December 23, 1893.

TURLOCK IRRIGATION DISTRICT.

This irrigation district was organized in April, 1887, under favorable auspices. There was but little opposition. Mr. George Manuel was made district engineer and estimated the cost of the necessary works at $467,545. Bonds were issued in the amount of $600,000, and when it became apparent that this sum would not cover the cost of the works an additional issue of $600,000 was made. Pending protracted litigation and the negotiations with the Modesto irrigation district relating to its participation in the construction of a high dam above Lagrange, the work on the main canal was pushed as rapidly as possible; but it is not even yet completed.

This district lies on the south side of Tuolumne River, extending southward to near Merced River and from the western edge of the Sierra Nevada foothills westward to near San Joaquin River. It has an area of 176,210 acres, of which about 30,000 are in Merced County, and the remainder in Stanislaus County. The land in the district is generally

held in tracts of less than 1,000 acres, practically all of which are grain farms. The soil is generally a sandy loam, fertile with moisture, producing fair crops of cereals when the rainfall reaches 10 inches, favorably distributed through the season; but on the whole there has been little profit in wheat farming.

Water is to be taken from above the Lagrange Dam by a tunnel 560 feet long, 12 feet wide, and 11 feet high, with vertical sides, and a radius of arch of 6 feet. It was originally proposed to place the regulator and a waste gate at the lower end of this tunnel, but this idea was abandoned and a regulating gate has been constructed at its inlet. For over a mile below the head-works tunnel the canal winds along a slaty hillside. The canal has there been constructed with a bed width of 20 feet and a proposed water depth of 10 feet. The outside canal bank is constructed of dry-laid rock retaining walls with clay puddle core. At the lower end of this hillside work the canal crosses Snake Ravine, which was closed by a dam and up which the canal water is to be turned for about 1,000 feet. The earth dam has been washed out, and the pond which it was to form is to be replaced by a flume. Thence the course of the canal leads through a cut about 800 feet long, made by the hydraulic process, and its water is dropped into old mining pits, in which it is held for a distance of about 2,000 feet. This canal section is followed by a rock cut 860 feet long, leading into Dry Creek. The channel of Dry Creek is utilized for 1¼ miles, and this creek section of the canal is followed by a flume. In its course farther westward the canal pierces three foothill spurs in tunnels, none of which are lined. Below the last of these tunnels the canal crosses a gulch, which is to be closed with a concrete dam 40 feet high, and the canal then enters another cut 3,300 feet long. It will cross Peasley Creek in a flume 20 feet wide and 7 feet deep.

The canal below Peasley Creek is generally 45 feet wide on the bottom and 7½ feet deep, and has a fall of 1 foot to the mile; but dimensions are not uniform, being varied to suit the character of material into which the canal is cut. The canal capacity as reported by the district engineer is 1,500 second-feet. Great care has been taken to keep canal dimensions uniform and to bring the canal bed to grade, often necessitating the taking of material from borrow pits at the outer levee base, thereby increasing the apparent height of canal levees and greatly increasing the danger of breaks in these embankments. There would have been no objection, so far as simple inspection discloses, to deepening the canal below grade where necessary to secure material, and the cause for adopting the above type of cross section has not been made apparent. Drops or check gates have been constructed where material is liable to erosion and the natural fall exceeds that prescribed for the canal. The canal approaches some of these between high levees and leaves them in moderate cut—a questionable arrangement. It might even be better to bring the canal into service without the use of drops

and to place these later where required. The main canal is 18 miles long and will supply water to five principal laterals, which are to have an aggregate length of 80 miles. These are to be 30 feet wide on the bottom and 5 feet deep, and are to have an effective fall of 2 feet to the mile. Other branch ditches of smaller dimensions, to the extent of 180 miles in aggregate length, are also to be constructed by the district. As the surface of the district is very smooth and the fall quite uniform from northeast to southwest, most of the branch canals will be constructed on land lines from north to south and from east to west. It is understood that a contract for the completion of this entire system of ditches, including the main canal, has been let, and that work is to be actively pushed under this contract.[1]

MODESTO IRRIGATION DISTRICT.

Soon after the project of organizing the Turlock district had taken definite shape, the farmers on the north side of Tuolumne River resolved upon the formation of a second district to be dependent on that stream for its water. Although considerable opposition was encountered, the result of their action was the formation of the Modesto irrigation district, which was consummated in July, 1887. The district extended northward from Tuolumne River to Stanislaus River, and from the foothills westward into the trough of the valley to near San Joaquin River. It had an area of about 108,000 acres. The preliminary study indicated conclusively that the expense of constructing a canal from Tuolumne River to command the entire district would be prohibitory, and that either the high southeastern portion of the original district must be excluded or that water must be taken from Stanislaus River at an estimated cost of over $700,000. Before further steps were taken bonds to the amount of $800,000 were voted, and a reduction of the area of the district to 81,500 acres soon followed. The project for the irrigation of the district lands did not assume its final definite shape until an arrangement was entered into with the Turlock irrigation district, according to which the two districts were to unite in constructing a great diverting dam in Tuolumne River about 1½ miles above Lagrange, and agreed to contribute equally toward its construction.

The canal has an inlet capacity of about 750 second-feet. Now hanging on hillsides, now following table-lands or mesas, or penetrating low spurs of the foothills in tunnels, it reaches a point near Waterford, with a total length of 23 miles. The canal regulator or head gate is in place and main canal excavation is reported finished, but other structures are incomplete or wanting, such as check weirs, flumes along steep hillsides and over creeks and gulches, and road bridges. This, including one-half the cost of the Lagrange Dam, has been accom-

[1] For further description of this canal, see American irrigation engineering, by H. M. Wilson: Thirteenth Ann. Rept. U. S. Geol. Survey, Part III, 1893, pp. 203, 232.

plished, under district management, with an expenditure, expressed in bonds sold, of the entire first issue of $800,000. The result is hardly more satisfactory than in many other of the irrigation districts. The district is not yet in position to furnish water to any of its lands; the cost of the work has been excessive, owing largely to the uncertainty of pay on completion, which deterred contractors in the case of nearly all district work in this and other irrigation districts from making low bids. Several years ago additional bonds to the amount of $350,000 were voted by the district, but these are to be withheld from sale pending final settlement of matters that have involved the district in litigation.

The surface of the district is admirably adapted for cultivation by irrigation. The soils are sands and sandy loams, and the ground has a slope from east to west of 5 to 10 feet to the mile. The entire area of this district, as well as of the Turlock district, was originally a treeless plain. For many years past it has been a vast wheat field.

STANISLAUS RIVER.

HYDROGRAPHY.

Stanislaus River is of the same type as the Merced and the Tuolumne, and of equal rank as a source of supply for large irrigation canals. Its mountain watershed has an area of 1,051 square miles, the run-off from which is ordinarily greatest in May, when snows are melting. The stream is at a low stage from August to December. During the winter months its flow is variable, being greatly influenced by rainfall and temperature. Its mean monthly discharge increases rapidly from January to April. From April to June is the period of its spring rise. The low-water flow is ordinarily from 100 to 200 second-feet, and the mean flow during the spring rise is 3,000 to 5,000 second-feet.[1] At Oakdale, where the river enters San Joaquin Valley, its bed is depressed about 80 feet below the general surface of the main valley plain. The river's low banks are flanked on either side by narrow strips of bottom land, which extend from river to base of the slope rising to the higher level of the upland. For over 40 miles below Oakdale the river surface is thus depressed below the level of the valley lands, but the difference in level gradually decreases, and near the trough of the valley the bottom lands of the river are merged into the submersible portion of the east-side plain.

Irrigation from this river has been confined to the foothill region until the enlargement and extension of an old ditch within the last two years has made water available on the north-side upland.

The United States Geological Survey has maintained a gaging station on this river since June, 1895. It is located at the highway bridge

[1] See Physical Data and Statistics, W. H. Hall, State engineer of California, 1886, pp. 428, 476.

just above the bridge of the Southern Pacific Company at the town of Oakdale.[1]

The following facts are brought out from this record:

The low-water flow for 1895, occurring in August, September, and October, was 145 second-feet.

1896. Maximum discharge, May, 13,050 second-feet; minimum, January, 150 second-feet; average for the year, 1,935 second-feet.

1897. Maximum discharge, February 4, 10,580 second-feet; minimum, September and October, 140 second-feet; average for the year, 1,835 second-feet.

Estimated monthly discharge of Stanislaus River at Oakdale, California.

[Drainage area, 1,051 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth in inches.	Second-feet per square mile.
1895.						
June	8,510	3,842	5,686	338,340	6.038	5.410
July	3,842	550	1,778	109,330	1.950	1.692
August	550	145	330	20,304	.362	0.314
September	3,161	145	638	37,970	.677	0.607
October	246	145	176	10,802	.193	0.167
November	179	179	179	10,651	.190	0.170
December	414	145	198	12,208	.218	0.189
1896.						
January	6,956	150	1,806	111,058	1.98	1.72
February	1,208	632	782	45,038	0.80	0.75
March	12,000	694	2,464	151,505	2.70	2.35
April	9,050	1,966	3,274	194,870	3.48	3.11
May	13,050	2,290	4,717	290,092	5.17	4.57
June	11,000	2,656	6,541	389,247	6.97	6.22
July	3,156	470	1,293	79,503	1.42	1.23
August	2,412	218	385	23,703	0.42	0.37
September	962	252	332	19,761	0.35	0.32
October	370	218	239	14,695	0.26	0.22
November	4,514	252	705	41,968	0.75	0.67
December	1,750	470	681	41,904	0.75	0.65
The year	13,050	150	1,935	1,403,344	25.05	1.85
1897.						
January	2,251	410	609	37,446	0.67	0.58
February	10,580	1,264	3,252	180,607	3.23	3.10
March	5,062	1,264	1,915	117,750	2.10	1.82
April	9,234	1,880	5,064	301,328	5.37	4.81
May	9,980	5,480	7,324	450,338	8.04	6.97
June	3,974	860	2,077	123,590	2.21	1.98
July	1,180	250	582	35,786	0.63	0.55
August	230	170	198	12,175	0.22	0.19
September	190	140	152	9,045	0.16	0.14
October	250	140	176	10,822	0.20	0.17
November	780	170	255	15,174	0.27	0.24
December	1,516	210	411	25,272	0.45	0.39
The year	10,580	140	1,835	1,319,333	23.55	1.74

[1] Bull. U. S. Geol. Survey No. 140, 1896, p. 305; Eighteenth Ann. Rept., Part IV, 1897, p. 371; Water-Supply and Irrigation Paper No. 11, 1897, p. 90; Water-Supply and Irrigation Paper No. 16, 1898, p. 187.

FIG. 14.—Discharge of Stanislaus River at Oakdale, California, 1896–98.

CANALS AND DITCHES.

Stanislaus & San Joaquin Canal.—Among the ditches constructed as aids to placer and river-bed mining over forty years ago was one on the north side of Stanislaus River, constructed by the San Joaquin County Water Company. Water was diverted from the river about 7 miles above Knights Ferry and was carried in ditch and flumes along the broken northern wall of the river canyon to points at and near Knights Ferry, where the ditch water had attained an elevation of 150 feet above the river surface. The ditch constructed by this company in 1854 to 1856 has remained in service ever since. As the demand for water from miners decreased, the demand from irrigators increased. Many projects for the diversion of a greater quantity of water than that represented by the old ditch capacity were proposed, but none

were pushed to completion, until finally, under new management, an enlargement and extension of the old work was successfully accomplished within the last few years, and is now known as the Stanislaus & San Joaquin Canal.

The old ditch before enlargement had somewhat irregular dimensions. It was generally 4 feet wide on the bottom, about 5 feet at the top, and carried water 2 feet deep. Its fall was not uniform, generally about 5 feet to the mile. Its capacity was about 15 second-feet. A dam was constructed across Stanislaus River at its head in several sections, closing the spaces between high projecting points of bed rock. The spaces into which these divided the river bed were closed by means of timber crib work having a crest length of about 300 feet and an average height of about 16 feet. It raises the water surface of the river 12 to 14 feet. A portion of this dam was renewed in the years 1877 to 1880.

The north-bank end of the dam rests against a high timber crib filled with rock, which is perforated for the ditch. The inflow into the ditch is controlled by means of a gate operated with a winch. When it was decided to increase the capacity of the original ditch, about 1888, work was commenced by a new organization, known as the San Joaquin Land and Water Company, on a masonry dam 4,300 feet below the present head of the ditch, but the structure has not been completed.

The old ditch for nearly a mile below its head had a position below the extreme limit of the river's flood plane. It has therefore frequently been cut out or filled with sand during the river's high stages, and its owners have been put to much trouble in keeping this upper section open. At 3 or 4 miles below its head the ditch was carried for over 1,000 feet along a smooth-surfaced vertical cliff in a hanging flume, whose iron supports were firmly anchored to the solid rock. The ditch at Knights Landing was at such elevation that but a short tunnel was necessary to carry a branch northward through the divide into Little Creek Valley. Its water was there used in one of the pioneer vineyards of the State, the property of Judge Schell. The original cost of the old ditch was $80,000. At the time it was superseded by the new work its waters were being used on 200 to 300 acres of orchard, vineyard, and garden land.

As a matter of history, reference may be made in this connection to the Farmington Water Company, whose works were intended to supplant those of the older ditch. This company, with Colonel Bulkley as chief engineer, proposed to construct a loose-rock dam across Stanislaus River one-quarter mile above the head of the San Joaquin County ditch and to turn the river through a rock cut past the south end of the dam. The location selected as a dam site was a favorable one, but the route from the dam for a large canal for 2 or 3 miles to the point where it was proposed to construct a tunnel through the ridge between the river and Little John Creek was not favorable. The construction of the

tunnel was, however, commenced, and it was driven into the mountain 700 feet from its south end and 200 feet from its north end. The length of the finished tunnel would have been 1,940 feet. This work was done in 1874 and 1875, but was not carried to completion, because the necessary financial arrangements could not be made.

The successive failures to accomplish a diversion of Stanislaus River water in a large north-side ditch, including a number that did not progress far beyond the recording of a claim to water, did not deter the Stanislaus and San Joaquin Water Company from undertaking the work.

The canal as it came into service in 1896 received water through an upper ditch extending from the diverting dam to the proposed new dam, 8 feet wide on the bottom, sides nearly vertical, water depth 5 feet, and a fall of a little over 4 feet to the mile. Below the partially built new dam the ditch for a distance of 900 feet is 9 feet wide on the bottom and its water depth was increased to 6 feet. The canal then enters a flume 1,112 feet long, thence flows through a tunnel 1,047 feet long, thence for 1,520 feet in another flume, from which it is delivered into a second tunnel 1,037 feet in length, and thence by ditch and flumes to a point to the north of Knights Ferry, where the Farmington Branch is sent off practically on the line of the old Schell Ditch to Little John Creek.

The main ditch is carried from there in a flume half a mile long across the depression to the north of Knights Ferry, thence by short ditch into a natural channel, in which it flows westward several miles, thence again in ditch and flumes alternately to a point about 11 miles west of Knights Ferry, where a distribution of its water is to be made to three branch ditches or laterals; of these one, the Escalon lateral, is to supply water to the uplands near Stanislaus River; a second, occupying the natural channel known as Lone Tree Slough and continued as Lathrop lateral, will command the main body of land intermediate between French Camp Creek and Stanislaus River; and the third, taking a northwesterly course, is to skirt the foothill base. From the main ditch a flume, in part supported by a bridge, has been carried across Stanislaus River for the delivery to Oakdale of 80 second-feet of water.

The Farmington Branch flows in Little John Creek about 11 miles, thence in a ditch on the north side of the creek 12 miles, reaching and extending upon the valley plain to the northwest of Farmington. It is 8 feet wide on the bottom, will carry water 2 feet deep, and has a fall of 1½ feet to the mile. The Escalon and Lathrop laterals are 14 and 24 feet wide, respectively. They were not complete in 1896, neither had the proposed Clyde lateral been constructed.

The upper two flumes on the main canal are 10 feet wide by 6 feet deep. These are followed by three flumes 8 feet wide by 8 feet deep. The gradient of main flumes varies from 1.9 to nearly 2.5 feet in 1,000.

The flumes below Knights Ferry generally are 8 feet wide and 6 feet deep, on a grade of 1.6 feet in 1,000; but the long flume is an exception; it is 6 feet wide, 5 feet deep, and has a fall of 11.4 feet in 1,000. The upper tunnel is 12 feet wide, planned to carry water 6 feet deep, on a grade of 1.5 in 1,000. The second tunnel is 14 feet wide, but has a grade of only 1.1 in 1,000. Where the upper portion of the main ditch is in excavation it is an enlargement of the old ditch. The outer bank of the old ditch was not disturbed, the entire enlargement having been effected by deepening and by cutting into the hillside. The new ditch is 9 feet wide on the bottom; it is to carry a maximum depth of 6 feet of water, and its fall is 0.9 foot in 1,000.

The great variability in capacity which the above dimensions indicate is to be accounted for in a measure by the fact that further enlargement is contemplated and that the new work was fitted to the old, as circumstances permitted. The total expense of canal enlargement, not including engineering nor rights of way, was about $150,000.[1]

Water is being furnished to irrigators very nearly on the same plan as that adopted by the Fresno and Crocker-Huffman companies, and long before water was available for delivery contracts were entered into between farmers and the canal company according to which the landowner pledged himself to take water for a specified tract of land as soon as water was available, and to pay therefor a bonus of $10 per acre, in deferred payments, at the rate of 50 cents per acre per annum, with interest at 6 per cent per annum on the amount remaining unpaid. The takers of water rights, in addition to the payment of this bonus, also obligate themselves to pay an annual water rental at the rate of $1.50 per acre. But the rate per acre is to become due during the first four years on only so much of the land as is actually irrigated; on not less, however, than one-fourth of the entire area the first year after water is available, on one-half the second year, on three-fourths the third year, and on the full acreage the fourth year and thereafter. The water rights issued at the beginning of 1896 covered about 14,000 acres. No information is available as to extent of irrigation during the first season.

Knights Ferry & Table Mountain Ditch (also known as *Pentland Ditch*).—This ditch, which has been out of service since 1881, is mentioned because before its final abandonment it supplied water to a few acres of orchard, vineyard, and garden land on the south side of Stanislaus River, opposite Knights Ferry. This ditch was constructed for mining purposes in 1855, at a reported cost of $210,000. Its head was at Sixmile Bar, about a mile below the head of the San Joaquin County Ditch. At that point a log dam, 30 feet in maximum height, enabled diversion into the ditch, which was cut into the south canyon wall. The location was not favorable for a ditch; flumes had to be used at a number of points, and at others the ditch was supported by

[1] The above facts relative to the work done by the new water company are largely from the published report on the work by Prof. George Davidson.

a high outside wall of dry rubble. The flumes were 4½ feet wide and 2 feet deep. The ditch was about 8 miles long; it had a fall of about 8 feet to the mile. Its capacity was about 20 second-feet.

Oakdale Canal.—From a point on the south side of Stanislaus River about a mile below Knights Ferry, a canal has been constructed to Oakdale. It has a total length of about 12 miles, and commands the low mesa, or second bottom, on which the town of Oakdale is situated. The construction of this canal was commenced about 1888, but much difficulty was experienced in making the diversion. At its head a loose-rock dam was to be maintained in the river. This was constructed of large blocks of rock, which were abundant near the dam site, and it was expected that, if piled into the river in sufficient quantity, they would form a riffle or sill above which water would be at sufficient elevation to be forced into the canal. The low-water plane of the river was to be raised by the structure about 8 feet. Seven years after the first construction of this dam the river was still annually breaking through it, and arrangements were then made with the Stanislaus and San Joaquin Water Company to take water to the extent of 80 second-feet from the canal of that company. This water is delivered to the Oakdale Canal at a point some distance above Oakdale, through a flume which spans the river.

MOKELUMNE RIVER.

HYDROGRAPHY.

Mokelumne River is the most northerly of the Sierra Nevada streams which are directly tributary to San Joaquin River. Its mountain drainage basin has an area of 657 square miles. In character it does not differ materially from the Stanislaus, the Tuolumne, and the Merced. Its bottom lands are nearly as extensive as those of Merced River, but do not lie in so compact a body. They extend well into the foothill region and westward to near Woodbridge. At that point there is a gradual merging of the upland and river bottom, this point being at the eastern limit of lands naturally subject to inundation.

The river is subject to the usual freshet flow of all Sierra Nevada rivers in winter, and has a pronounced high stage late in spring, due to the melting of snow. Its flow in April, May, and June is generally 3,000 to 4,000 second-feet. At its lowest stage, in the fall of the year, it brings less than 100 second-feet of water into the main valley.[1] The lesser drainage area of this river when compared with the others of its class is offset in a measure by greater rainfall throughout its watershed.

The Southern Pacific Company commenced observations of gage heights on this river in 1879 at their bridge at Lodi. The United States Geological Survey made a number of measurements of discharge

[1] See Physical Data and Statistics, W. H. Hall, State engineer of California, pp. 422, 476.

at that point, but, owing to the poor character of the section, results were not altogether satisfactory and the station was discontinued. For results of the work at this point see various reports of the Survey.[1]

CANALS AND PROJECTS.

As most of the water of this river flows idly to the sea, it is not without interest to inquire why the water is not utilized, particularly as the upland on both sides of the stream is a friable sandy loam of excellent quality, well adapted for irrigation.

The rainfall of this portion of San Joaquin Valley is about 15 to 20 inches per annum, enough to permit cultivation of cereals by methods of dry farming, and even to make orchards and vineyards yield a fair return. The demand for water has never, therefore, been very imperative. On the other hand, many projects have been discussed or partially executed, but, on account of engineering and financial difficulties, have met with entire or partial failure. The most notable project was that of the Mokelumne Ditch and Irrigation Company, which, under its original organization, commenced but did not finish the construction of a high masonry overfall dam or weir at the Westmoreland bridge near Lancha Plana. After many years of inaction work was again undertaken in 1887. The dam was then raised and repaired and work on the canal was commenced. It was proposed to carry water in a large canal on the south side of the river along and through the hills into Bear Creek, and thence to the eastern border of the valley lands, where it was to be put into a system of branch ditches or canals. The project failed for lack of funds.

A few years later the farmers living near the eastern margin of the flood limit of the valley, between Stockton and Mokelumne River, gave sufficient encouragement to the Woodbridge Canal Company to warrant the construction of their proposed canal. The river was brought under control and raised at Woodbridge by a series of gates, equivalent to a movable dam, from above which a canal was cut toward the south. The canal came into use in 1891, but the demand for water was not so great as had been anticipated. Financial difficulties increased from year to year, and accidents happened to the head works, so that this canal also is again out of service. The irrigation with water from the river, therefore, is practically confined to a few acres of bottom land served by small neighborhood ditches, such as the Bahmert Ditch, on the north side of the river some miles above Clement. The principal mountain ditches which are fed by the river and its tributaries are still in service for mining and domestic use rather than for irrigation.

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[1] Twelfth Ann. Rept. U. S. Geol. Survey, Part II, 1891, p. 323, Pl. LXXXVII; Bull. No. 131, 1895, p. 86; Bull. No. 140, 1896, p. 308.

WEST-SIDE CREEKS AND OTHER STREAMS OF SAN JOAQUIN VALLEY.

From this account of irrigation in San Joaquin Valley it will appear that here, as well as in the State at large, irrigation is a local rather than a general aid to farming operations, and that ample opportunity remains for further development. This is particularly true of the most northerly portion of the valley, and applies with increasing force to Sacramento Valley, where irrigation has thus far barely secured a foothold. It remains to be said, however, that the foregoing chapters are not to be considered exhaustive, because neither time nor means at command permitted a revisit to the entire field, and little or no attention has been given to the lesser irrigation work from small creeks intermediate between the more important streams.

On the west side of the valley are a number of small irrigation works which draw their supply from the creeks of the Coast Range. These streams are torrential in character. Their flow is occasionally considerable during severe storms, but it is of brief duration. Ordinarily the run-off is very slight, and in many winters the streams remain almost unaffected by the light fall of rain on the eastern slopes of the Coast Range. This uncertainty of supply interferes with attempts to bring them under control for irrigation purposes. Here and there, however, some success has been had, particularly on those creeks having the largest drainage basins. This has been the case on Los Gatos Creek just above Huron, which has a drainage area of 441 square miles. The bed of this creek some miles above Huron remains moist during summer, and diverting works there constructed (in part at least of sheet piling, nearly equivalent to a submerged dam) have developed a flow of 6 to 8 second-feet for the Pleasant Valley Ditch, which is a private ditch in use for the irrigation of a tract of alfalfa.

The favorable indications near the head of this ditch for the development of a larger water supply encouraged the farmers to the east of Huron to form an irrigation district, which was organized in 1891. It is known as the Huron irrigation district, and has an area of about 20,000 acres. A plan of works was adopted, but no bonds were sold and no construction work has been done.

Notable among great works projected but not carried out was the west-side canal, which was to have been fed with water from Tulare Lake, it having been assumed at the time the project was under discussion, in 1876 and 1877, that the lake could be relied on to overflow annually. As there has been no such overflow for about twenty years, it appears fortunate that the project was not undertaken.

The subject of irrigation and water development from artesian wells should not be entirely neglected in treating of irrigation in San Joaquin Valley, but space will not permit of its consideration in this paper. For information on the subject reference may be made to the special bulletin of the Eleventh Census, Report on Agriculture by Irrigation in the Western Part of the United States, by F. H. Newell, page 50.

INDEX.

	Page.
Adobe Ranch Ditch, description of	31
Adobe Slough, figure showing head of	30
Blyth Canal, plate showing	24
description of	25
Buchanan Reservoir project, description of	32–33
Chowchilla Canal, description of	15–18
plan and section of regulator of	16
Chowchilla River, hydrography of	31
irrigation from	31–33
Cost of irrigation	21, 22, 29–32, 36
Crocker-Huffman Canal, description of	34–37
plates showing features of	34–36
Dean Ditch, description of	38
Dos Palos Canal, description of	24
East Side Canal, description of	25
Farmers Canal, description of	34
Feldhaus & Reed Ditch, description of	39
Fresno River, hydrography of	26
irrigation from	27–31
Fresno River Dam and Canal Company, operations of	27–30
figure showing canal of	27
Griffith & Shaver Ditch, description of	39
Hall, W. H., cited	10, 15, 17, 33, 40, 50
Hamlin Ditch, description of	39
Herndon, stream measurements at	10–11, 12
Ingalsbe Slough, description of	38
Irrigation, acreage under	20, 29, 37
cost of	21, 22, 29–32, 36
methods of	22, 29, 32, 40
Knights Ferry & Table Mountain Ditch, description of	55–56
Kohler, West & Minturn Canal, description of	31–32
figure showing water diversion by	32
Lagrange, stream measurements at	42–43
Lagrange Dam, plates showing	44, 46
description of	45–47
figures showing plan and section of	45, 46
Lagrange Ditch, description of	43–44
Madera Canal, description of	27–30
figure showing head of	27
Madera Canal and Irrigating Company, operations of	30
Madera irrigation district, work in	14–15
Means Ditch, description of	39
Merced Canal, description of	34–37
Merced Falls, water power utilized at	37
Merced Falls Ditch, description of	37
Merced Reservoir, description of	35
plate showing inlet to	38
Merced River, hydrography of	33
irrigation from	34–40
plate showing dam across	34
Miller & Lux, irrigation by	20–22, 24
Millrace Ditch, description of	39
Minturn, irrigation near	31
Modesto, stream measurements at	41–42
Modesto irrigation district, work in	45, 49–50
Mokelumne Ditch and Irrigation Company, operations of	57
Mokelumne River, hydrography of	56–57
irrigation from	57
Montgomery & Anderson Ditch, description of	38
Montgomery Ditch, description of	39
Murray Mill Ditch, description of	37–38
Newell, F. H., letter of transmittal by	7
cited	58
Oakdale, stream measurements at	51–52
Oakdale Canal, description of	56
Old River, irrigation from	38–39
Patricksville Reservoir, description of	44
Pentland Ditch, description of	55–56
Pleasant Valley Ditch, description of	58
Posey Slough, description of	24
San Joaquin & Kings River Canal, description of	18–23
figure showing head of	18
figure showing head works of	19
plate showing regulator in	22
San Joaquin County Water Company, operations of	52
San Joaquin Land and Water Company, operations of	53
San Joaquin River, hydrography of	9–12
diagram showing discharge of	12
irrigation from	13–26
figure showing dam across	20
plate showing steamboat chute on	20
San Joaquin Valley, map of	32
irrigation from west-side creeks of	58
Sanjon de Santa Rita, description of	24
Schuyler, J. D., quoted	15–16, 21–22
Scott Ditch, description of	38
Sillman & Ruddle Ditch, description of	39
Snelling Ditch, description of	38
Stanislaus & San Joaquin Canal, description of	52–55
Stanislaus River, hydrography of	50–52
irrigation from	52–56
diagram showing discharge of	52
Stevenson-Mitchell Canal, description of	25
Temple Slough, description of	24
Tuolumne River, hydrography of	40–43
diagram showing discharge of	42, 43
irrigation from	43–50
Turlock irrigation district, work in	45, 47–49
Upper San Joaquin River Canal, description of	13–14
figure showing head of	13
Water, methods of diversion and use of	39–40
Wheaton Ditch, description of	44
Wilson, H. M., cited	33, 49
Woodbridge Canal Company, operations of	57

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DEPARTMENT OF THE INTERIOR

WATER-SUPPLY

AND

IRRIGATION PAPERS

OF THE

UNITED STATES GEOLOGICAL SURVEY

No. 20

EXPERIMENTS WITH WINDMILLS.—PERRY

WASHINGTON
GOVERNMENT PRINTING OFFICE
1899

UNITED STATES GEOLOGICAL SURVEY

CHARLES D. WALCOTT, DIRECTOR

EXPERIMENTS WITH WINDMILLS

BY

THOMAS O. PERRY

WASHINGTON

GOVERNMENT PRINTING OFFICE

1899

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CONTENTS.

	Page.
Letter of transmittal	9
Introduction by F. H. Newell	11
General statement	19
Apparatus	21
Angle of weather	22
Artificial wind	22
Dynamometer	23
Method of experiment	24
Starting forces	25
Journal friction	25
Comparative standard wheel	27
Results of original tests	28
Tables and descriptions of wind wheels	28
Wheel No. 1	28
Wheel No. 2	29
Wheel No. 3	31
Wheel No. 4	33
Wheel No. 5	34
Wheel No. 6	34
Wheel No. 7	36
Wheel No. 8	37
Wheel No. 9	37
Wheel No. 10	38
Wheel No. 11	38
Wheel No. 12	39
Wheel No. 13	39
Wheel No. 14	40
Wheel No. 15	40
Wheel No. 16	41
Comparative results with plain sails	41
Wheel No. 17	43
Wheel No. 18	43
Wheel No. 19	44
Wheel No. 23	46
Comparison of several wheels	46
Wheels Nos. 2 and 50	46
Wheels Nos. 18, 19, 20, 21, and 22	47
Wheels Nos. 24, 25, 26, 27, and 28	47
Wheels Nos. 29, 30, 31, 32, and 33	49
Wheels Nos. 19, 20, and 34	51
Wheels Nos. 35, 36, 37, and 38	51
Wheels Nos. 40, 41, 42, and 43	53
Wheels Nos. 40, 41, and 42	55
Wheels Nos. 35, 39, 40, and 44	57

Results of original tests—Continued. Page.
Comparison of several wheels—Continued.
Wheels Nos. 45, 46, 47, 48, and 49 ... 59
Wheels Nos. 2, 60, and 61 ... 61
Wheels Nos. 2, 49, 53, 54, 55, 56, and 57 ... 64
Wheels Nos. 2, 49, 51, 52, 58, and 59 ... 65
Sails at best angles of weather ... 65
Relations of three different velocities of wind ... 66
Automatic brake adjuster ... 67
Theory of the action of the wind upon the sails of windmills ... 69
Discussion of results ... 72
Thermometric and barometric influences ... 72
Construction of tables ... 73
Extreme results ... 73
Influence of outside wind ... 74
Standard of comparison ... 74
Corrections for axle friction ... 75
Aerial friction ... 76
Relation between speed and load ... 76
Best speeds for wind wheels ... 78
Best loads for wind wheels ... 78
Conical deflector in center of wheels ... 79
Air-cushioned sail surfaces ... 79
Obstructions on the back of sails ... 79
Waste of power due to the arms of wind wheels ... 80
Twisted sails ... 81
Deflectors in front of sails ... 81
Obstructions in front and in the rear of wind wheels ... 82
Maximum products in different velocities of wind ... 82
Starting forces and loads at the maximum in different velocities of wind ... 83
Speeds of unloaded wheels in different velocities of wind ... 83
Action of air on the sails of a wind wheel ... 84
Theoretical efficiency of the wind wheel ... 84
Theoretical useful effort of wind ... 87
Aerial resistance to motion ... 89
Best number of sails ... 90
Best relative areas of sail surface ... 90
Actual efficiency of the wind wheel ... 91
Work of variable wind with variable load ... 92
Regulation of wind wheels ... 92
Limitation to size of wind wheels on account of weight ... 93
Efficiency of wind wheels as affected by diameter ... 94
Height of towers ... 94
Multiplication of wind power ... 95
Power of a 12-foot wind wheel ... 95
Value of mathematical formulæ in experimental investigations ... 96
Index ... 97

ILLUSTRATIONS.

		Page.
PLATE	I. Windmill pumping water for irrigation	11
	II. Reservoir and garden	12
	III. Windmill and small reservoir	14
	IV. Small irrigation reservoir	14
	V. *A*, Homemade wind engine, as used on the Great Plains; *B*, The Defender windmill and water elevator	16
	VI. Elevation of apparatus used in wheel tests	20
	VII. Plan of apparatus used in wheel tests	20
	VIII. Plan and elevation of dynamometer	22
	IX. End views of dynamometer	24
	X. Windmill and reservoir	78
	XI. Windmill and reservoir	88
	XII. Windmill on low tower on the Great Plains	94
FIG.	1. Vertical section through reservoir and outlet	12
	2. Windmills and circular reservoir	13
	3. Steel windmill and tower carrying tank	14
	4. Irrigating ditch leading from earth reservoir filled by windmills	16
	5. Distribution of water to small beds	17
	6. Distribution system adapted to irregular land	17
	7. Elevation and section of wheel No. 2	30
	8. Outline of area not available	31
	9. Elevation and section of wheel No. 3	32
	10. Dimensions of sails of wheel No. 3	33
	11. Angles of weather of sails of wheel No. 3: *A*, Angle at inner ends of sails; *B*, Angle at outer ends of sails	33
	12. Elevation and section of wheel No. 6	35
	13. Dimensions of sails of wheel No. 6	36
	14. Dimensions of sails of wheel No. 18	44
	15. Elevation and section of wheel No. 19	45
	16. Elevation and section of wheel No. 24	48
	17. Elevation and section of wheel No. 29	50
	18. Elevation and section of wheel No. 35	52
	19. Dimensions of sails of wheels Nos. 35, 36, 37, and 38	53
	20. Elevation and section of wheel No. 40	54
	21. Dimensions of concave sails of wheels Nos. 40, 41, 42, and 43	55
	22. Elevation and section of wheel No. 39	56
	23. Dimensions of sails of wheel No. 39	57
	24. Elevation and section of wheel No. 44	58
	25. Elevation and section of wheel No. 48	60
	26. Dimensions of sails of wheels Nos. 45, 46, 47, 48, and 49	61

Page

FIG. 27. Elevation and section of wheel No. 60 62
28. Elevation and section of wheel No. 61 63
29. Dimensions of sails of wheel No. 61 with obstruction on back 64
30. Action of wind on a sail 70
31. Action of air on the sails of a wind wheel 84
32–35. Theoretical efficiency of the windmill 85
36–39. Theoretical useful effort of wind 87–88

LETTER OF TRANSMITTAL.

DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
DIVISION OF HYDROGRAPHY,
Washington, July 15, 1898.

SIR: I have the honor to transmit herewith a manuscript entitled Experiments with Windmills, prepared by Mr. Thomas O. Perry. These experiments, as described by Mr. Perry, were carried on during the years 1882 and 1883 for the United States Wind Engine and Pump Company, of Batavia, Illinois. As a result of these experiments radical changes and improvements were made in the windmills. As a matter of business policy the company did not desire that the results of these tests should be made known for some years. After the expiration of a certain time, however, the data have been placed at the disposal of the public through the kindness of the officers of the company and the efforts of Mr. Perry. Although as the result of this work great changes have been made in windmills, many of the suggestions made have not yet been put into practice and may serve as a foundation for further work along this line. The importance of the windmill as a means of utilizing the water resources of a part of the country is so great that all available information on the subject should be diffused and brought to the attention of persons who can make use of the facts. I respectfully request, therefore, that this manuscript, with a brief introduction, be printed as one of the series of pamphlets on water supply and irrigation.

Very respectfully,

F. H. NEWELL,
Hydrographer in Charge.

Hon. CHARLES D. WALCOTT,
Director United States Geological Survey.

WINDMILL PUMPING WATER FOR IRRIGATION

INTRODUCTION.

By F. H. NEWELL.

During the progress of investigation of the extent to which the arid lands can be reclaimed by irrigation and of the related question of the occurrence of water underground attention has been continually drawn to the practical methods of bringing the underground water to the surface. Throughout a great part of the arid and semiarid region there are localities where water can be obtained at a short distance from the surface. The amount, although not large in the aggregate when compared with the quantity in some notable stream or lake, is yet inexhaustible by the ordinary methods of pumping. If, therefore, this water which exists from 10 to 50 feet beneath the surface could be cheaply raised, it would be practicable to utilize for agriculture tracts which otherwise have little or no value.

The irrigation of 20 acres in the midst of a section or township of land is, figuratively speaking, a mere drop in the bucket; but the reclamation of this small area generally means the utilization of adjoining lands. If, for example, 20 acres of some forage crop like alfalfa is made possible, this will result in obtaining a considerable amount of winter feed used in the sustenance of a herd which can be pastured upon the surrounding dry land. The successful cultivation of this 20 acres may thus directly or indirectly support a family, and, with increased experience and adaptation to the surrounding conditions, the family may in turn give place to a rural community. Given the existence of sufficient water underground to irrigate the 20 acres, the first question is that of ways and means of bringing the water to the surface.

The force which is ever present, making itself persistently felt throughout the Great Plains region, is the wind, which blows almost continuously. It carries the dust before it, cuts out the traveled roads, carries away the fine earth of the tilled fields, and builds up a fine loess, almost everywhere to be found. The wind, which has so long been considered as an annoyance and mischief-maker, has sufficient strength to perform the work of bringing water to the surface, if only suitable means of directing its energy can be discovered.

The windmill is the best-known method of converting wind energy into work. In one form or another it has been used from times ante-

dating the dark ages. In the twelfth century windmills, built either by individuals or by communities, were common. Some of these mills were of enormous size. In the German type the whole building on which the mill was placed was constructed in such a manner as to turn on a post in order to bring the sails into the wind. In the Dutch form the building was fixed, but the head of the mill could be turned into the wind. The most notable use of these early mills was in Holland, where the land was drained by pumping water from behind the dikes into the sea. In 1391 the bishop of Utrecht, holding that the wind of the whole province belonged exclusively to him, gave to the convent at Windsheim express permission to build a windmill wherever it was thought proper. In so doing he overruled a neighboring lord who declared that the wind in the district belonged to him. Three years later the city of Haarlem obtained leave from Albert, Count Palatine of the Rhine, to build a windmill, using the wind of the country.[1]

FIG. 1.—Vertical section through reservoir and outlet.

The huge, clumsy windmills of European make, one of which was erected at Lawrence, Kansas, within the memory of the present inhabitants, have within a few decades given place in this country to the light, rapidly running forms. Thousands of these have been made by various firms throughout the country. At first wood was used almost exclusively, but this is being rapidly displaced by metal, especially by thin steel plates and forgings. Although millions of dollars have been invested in the manufacture and purchase of mills and much attention has been given to the mechanical details and the saving in weight and cost, yet comparatively little study has been bestowed upon the actual efficiency of the various forms and upon their development toward theoretical ideals.

A view of gardens cultivated by water pumped by windmills is shown in the accompanying plate (Pl. II). This picture has been taken from a windmill platform. In the foreground is a small reservoir, divided by a bank in the middle, so that one part may be used independently of the other. The part nearer the observer is the older; the second part is a recent addition, rendered necessary by the increase of the area cultivated. Without windmills the cultivation of the tract of country shown in this picture would be impossible. It is doubtful if a single cow could find subsistence on the area which now supports a family.

[1] The Windmill as a Prime Mover, by Alfred R. Wolff, p. 51.

RESERVOIR AND GARDEN

Another small reservoir and windmill is shown on Pl. III. This reservoir is in the corner of a small suburban truck farm, to which it furnishes water both for vegetables and trees. The owner has stocked a small pond with fish and from it obtains an ample supply for his own use. On the right-hand side is shown the outlet gate, through which water is discharged into a ditch, and that in turn empties into furrows running near the fruit trees and traversing the cultivated ground.

In fig. 1 is given a section through one of these small reservoirs, showing at the bottom the puddled earth or clay that prevents the water from seeping into the adjacent ground. On this puddled earth the banks are built at a height of from 4 to 10 feet. These are usually built by plowing and scraping up the earth from the outside, the tramping of the horses and the men serving to consolidate it. When the bank has been built to the proper height it is smoothed and sodded. On the right-hand side of the figure is the pipe or wooden flume from the windmill, and on the left-hand side is shown the outlet box, which is usually built of 2-inch plank. This is closed by some simple form of wooden gate or valve, either lifted by means of a screw or hinged so as to open outward, and is held in place by the pressure of the water against it.

FIG. 2.—Windmills and circular reservoir.

The square reservoir is the form usually adopted. The mills, as in the other cases, are placed on each side, pumping through short wooden flumes over the bank. These reservoirs are not only used for holding water for irrigation, but, as before stated, with a little care serve as ponds for raising fish.

A view of one of these small square reservoirs is shown on the accom-

panying plate (Pl. IV). The banks are obscured by the luxuriant growth of weeds. The surface of the water is a little higher than the general level of the land, so that a supply can be drawn by gravity directly to the adjacent fields.

Fig. 2 gives a nearer view of one of these earth reservoirs, which in this case has been built nearly circular in form. The two windmills which supply the water are placed upon opposite sides, in order that the pumps may be as far apart as possible. In many instances three or even four mills, each of moderate size, are placed around a reservoir of considerable size. The banks, made of earth, are covered with sod to protect them from washing by the rain and by the waves during times of high winds.

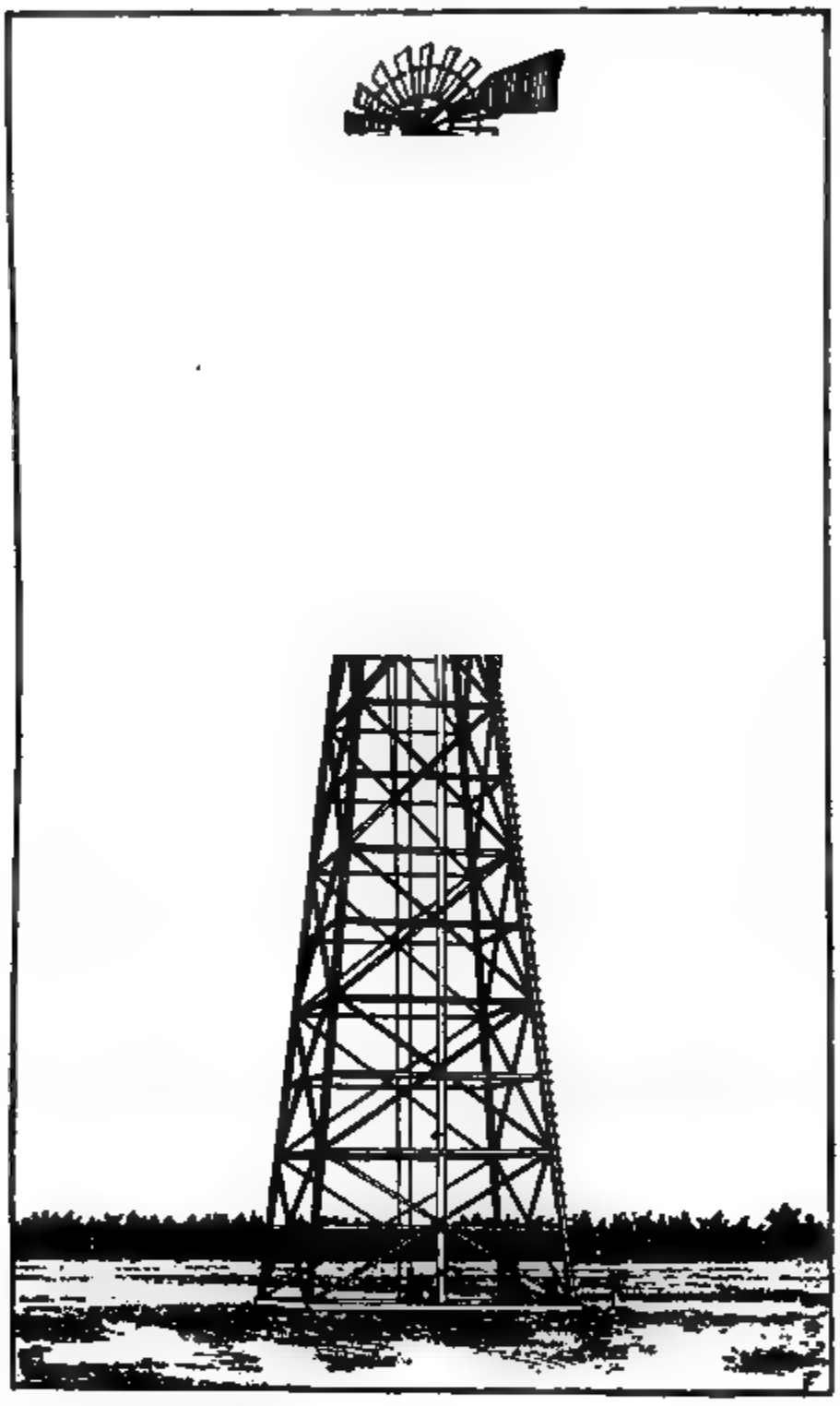
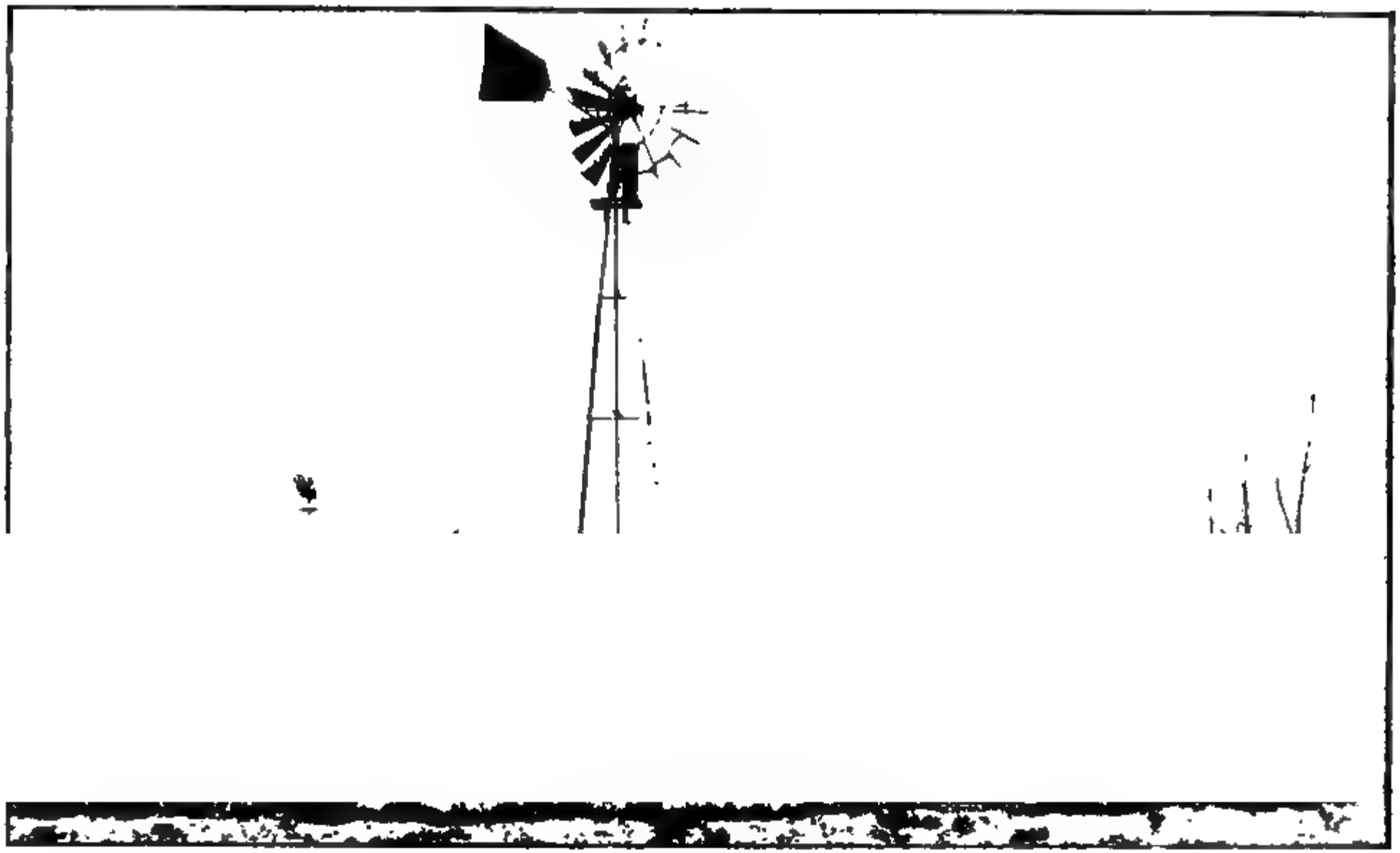


FIG. 3.—Steel windmill and tower carrying tank.

Fig. 3 represents an adaptation of a windmill for use in domestic water supply or for furnishing water to a village or small town under considerable pressure. The wind engine is erected on the top of a high steel tower, which also supports a wooden tank with suitable cover to protect the water from loss by evaporation. This device is generally employed by railroad companies at stations on the Great Plains, where the wind may be depended upon to force a sufficient supply into the tank for use by locomotives or for the railroad shops and offices. Many towns also depend for their water supply upon a windmill pumping water into an elevated tank, particularly where the general surface is so nearly level



WINDMILL AND SMALL RESERVOIR

SMALL IRRIGATION RESERVOIR

that it is impossible to construct a small earth reservoir within reasonable distance of the principal buildings.

The device shown in Pl. V, *A*, which has been employed to a considerable extent in the Great Plains region, is usually constructed by the owners. The merit of the device is its cheapness. It may be built mainly of old lumber and other material that can often be found about the farm, such as axles or other gear from old farm machinery, bale wire for staying the sails, and pieces of wood or metal which may be classed as old junk. The machine can not be recommended on the ground of efficiency or economy. If a farmer has sufficient capital to purchase and erect a good windmill he will undoubtedly succeed better than by spending his time in making the cheaper device. On the other hand, in situations where, as is often the case in a dry region, the farmer has lost crops year after year, has exhausted his resources, and is on the verge of bankruptcy, a contrivance of this kind may serve to save a small crop and give him a new start. In such instances there usually will be found pieces of broken-down machinery about the farm. Time and labor are commonly of little value where the ordinary farming operations have been unsuccessful, so that by the exercise of a little ingenuity the material and energy that otherwise would be wasted may be turned to advantage.

The mill or engine consists of a shaft of wood or iron placed horizontally and supported at each end. Upon this sails are fastened by arms extending out at right angles. On each end of the shaft is attached a crank, and each of these cranks in turn drives some simple form of homemade pump. The lower half of the mill is boxed in, and thus forms a small building without roof, above which project the arms carrying the sails.

As illustrating another homemade device, Pl. V, *B*, has been introduced. This mill and water elevator, invented by the owner, has been successfully used to furnish water for irrigation, and, although not by any means an economical device, nor one that can be recommended, it has served its purpose. In other words, while as a rule it is economical to purchase the best, there are circumstances and times when for special reasons the best mill can not be had, but it is still practicable to construct a machine which will accomplish the desired end, that of getting water from the ground upon the land.

These examples might be almost indefinitely multiplied, but are sufficient to demonstrate the principle that with energy and ingenuity a start toward irrigation can be made. When, however, some experience has been had in irrigation and newer mills are being procured, it is highly essential for continued success that something better than the ordinary form of mill be obtained. Many of these have been designed for some other purpose than that of raising large quantities of water through a short distance for irrigation. Some, for example, have been built with the idea of pumping a small quantity from great

depth for watering stock. Such mills, as a rule, do not fill the requirements of the irrigator. Thousands of windmills are in use and thousands more will be purchased, involving expenditures on the part of farmers aggregating millions of dollars. A saving of even a small percentage in cost and economy is therefore a matter of considerable importance in the continued development of the water resources of the country.

Fig. 4 shows two windmills so arranged as to pump into a reservoir built of earth, placed upon the highest part of a farm. Running night and day the pumps supply such a quantity of water to the reservoir that when needed a considerable volume can be drawn at once, filling

FIG. 4.—Irrigating ditch leading from earth reservoir filled by windmills.

a ditch of as large size as is ordinarily built for irrigating a field of from 10 to 20 acres.

Fig. 5 illustrates one of the methods used to distribute small quantities of water, such as may be had from the tank or reservoir of a windmill. In the drawing the banks are represented as made of cement or of wooden planks, such as are used in portions of California, where water has especial value. The usual practice, however, within the Great Plains region is to make the ditches of earth and to place the little gates in wooden frames. Sometimes instead of using gates the irrigator controls the water by shoveling earth into the ditches and furrows, backing up the water until it overflows the bank or comes out through on opening made by means of the shovel. As shown in the figure, the water flowing in the main stream from right to left is checked by small gates and forced to flow laterally through furrows,

A HOMEMADE WIND ENGINE, AS USED ON THE GREAT PLAINS.

B DEFENDER WINDMILL AND WATER ELEVATOR

and is again checked in these and forced out upon the beds lying on each side of the furrow. When a certain portion is wet the small gates are adjusted so as to force the water over other portions.

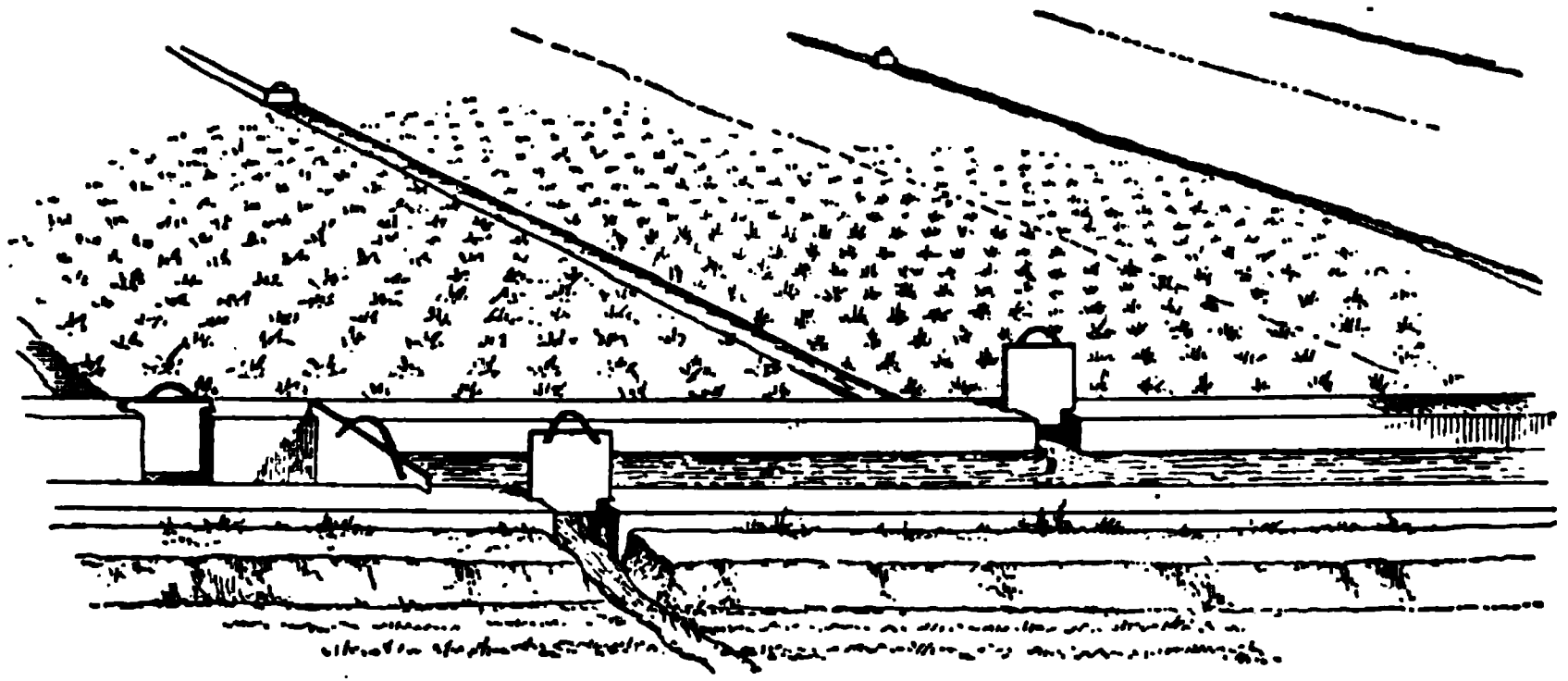


FIG. 5.—Distribution of water to small beds.

Where land has a decided fall or is rolling and it is too expensive to terrace, a system of distributing the water must be devised suited to the contour of the ground. In the case shown by the accompanying figure (fig. 6) the water enters the distributing ditches at the upper left-hand

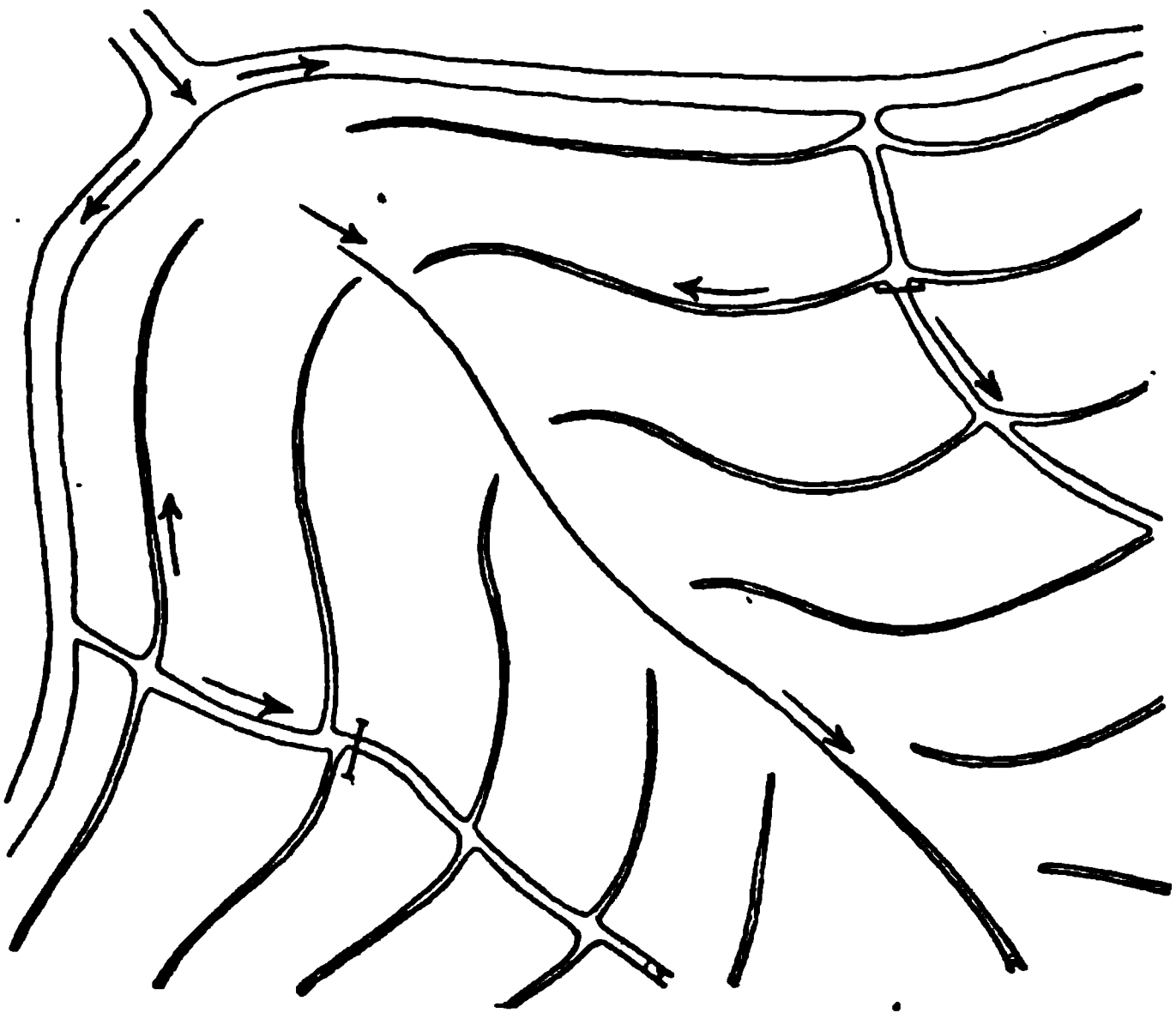


FIG. 6.—Distribution system adapted to irregular land.

corner and, dividing, flows through these and again into still smaller ditches, from which it is turned laterally into furrows. The flow is checked from point to point by little dams or temporary obstructions of

earth. After the water passes out upon a field any surplus is caught by a small trench shown in the figure as trending diagonally toward the right-hand lower corner, and from this in turn the water can be caused to flow out upon the lower fields, so that the excess or seepage from the higher portions is not wasted but is employed in the irrigation of the lower parts of the farm.

There are many other devices by which water pumped by windmills may be stored and distributed, but those briefly described above are among the most common. It is sufficient at this time to make mention of these in order to bring out the fact that experiment has demonstrated that it is practicable to irrigate land by water pumped by windmills. Many farmers in various parts of the United States are dependent for their living on this system of agriculture, and others are seeking to gain knowledge by which they may better their condition by providing a water supply for use in times of drought. This is true not only of the West, but of the East and the South, especially in regions where the soil, though fertile, is light and becomes dry if the rains do not occur with great regularity. Even on the Atlantic seaboard the early truck farmers are experimenting with devices of this character, copying methods which have already proved successful in Kansas. Modifications in mills and other machinery are doubtless necessary to suit local conditions. For a given purpose one mill may be far better than another, and of two wind engines similar in cost one may be actually worth two or three times as much as the other.

The dynamometric experiments carried on by Mr. Perry, as described in the following pages, have brought out many important points upon which depend the relative efficiency of various mills and the advantages of one type over another. Some of these points have already been considered and made use of in mills now on the market, while others of equal or greater importance are awaiting practical application and ingenuity. It is hoped that by the publication of these facts interest will be aroused and inventors will be stimulated to continue work along various lines, leading to further improvement and to a consequent cheapening of the cost of raising water by wind power.

EXPERIMENTS WITH WINDMILLS.

By THOMAS O. PERRY.

GENERAL STATEMENT.

The experiments with wind wheels described in the following pages were commenced June 1, 1882, and concluded September 15, 1883. At that time wind wheels in this country were nearly all made with narrow wooden slats for sails, set at various angles with the plane of the wheel, ranging from 35 to 45 degrees.

The slats were usually placed as close together as possible without having their projections on the plane of the wheel overlap. The proportions of sail surface and their angles of weather were apparently arrived at without any well-defined purpose. The only experiments made in the United States, so far as could be learned, related to starting forces only. They did not include the measurement of work in foot-pounds. The only well-defined experiments with wind wheels, the records of which were available, were those made in England by John Smeaton, F. R. S., about one hundred and twenty-five years before. Smeaton's paper, On the Construction and Effects of Windmill Sails, was read before the Royal Society May 31 and June 14, 1759, and to this day has remained the only definite available source of information on the subject treated. The paper was republished in Tredgold's Tracts on Hydraulics, a copy of which was received before these experiments were commenced.

It had been especially noted that Smeaton's angles of weather were much less than those in common use in this country, and note had also been taken of his statement to the effect that the work of a wind wheel is not increased, but diminished, by crowding it with sails so that their total surface exceeds about seven-eighths of the circular area containing them. The universal practice here was to crowd the wheel with slats until the total sail surface exceeded the total area of the annular zone containing them by more than one-fifth of the whole zone; according to Smeaton, this was adding to the greatest possible effective sail area more than 39 per cent additional area of worse than useless surface. If a large part of the material could be saved, and at the same time a considerable increase in power be effected, no slight

gain would be secured. Smeaton's experiments were made so long ago that they were disregarded, if they were ever noticed, by the builders of modern wind wheels. Our experiments fully confirmed Smeaton's results in regard to the greatest effective amount of sail area, although we do not necessarily accept Smeaton's judgment that it is not profitable to increase the total area of sails beyond about 37 per cent of the annular zone containing them.

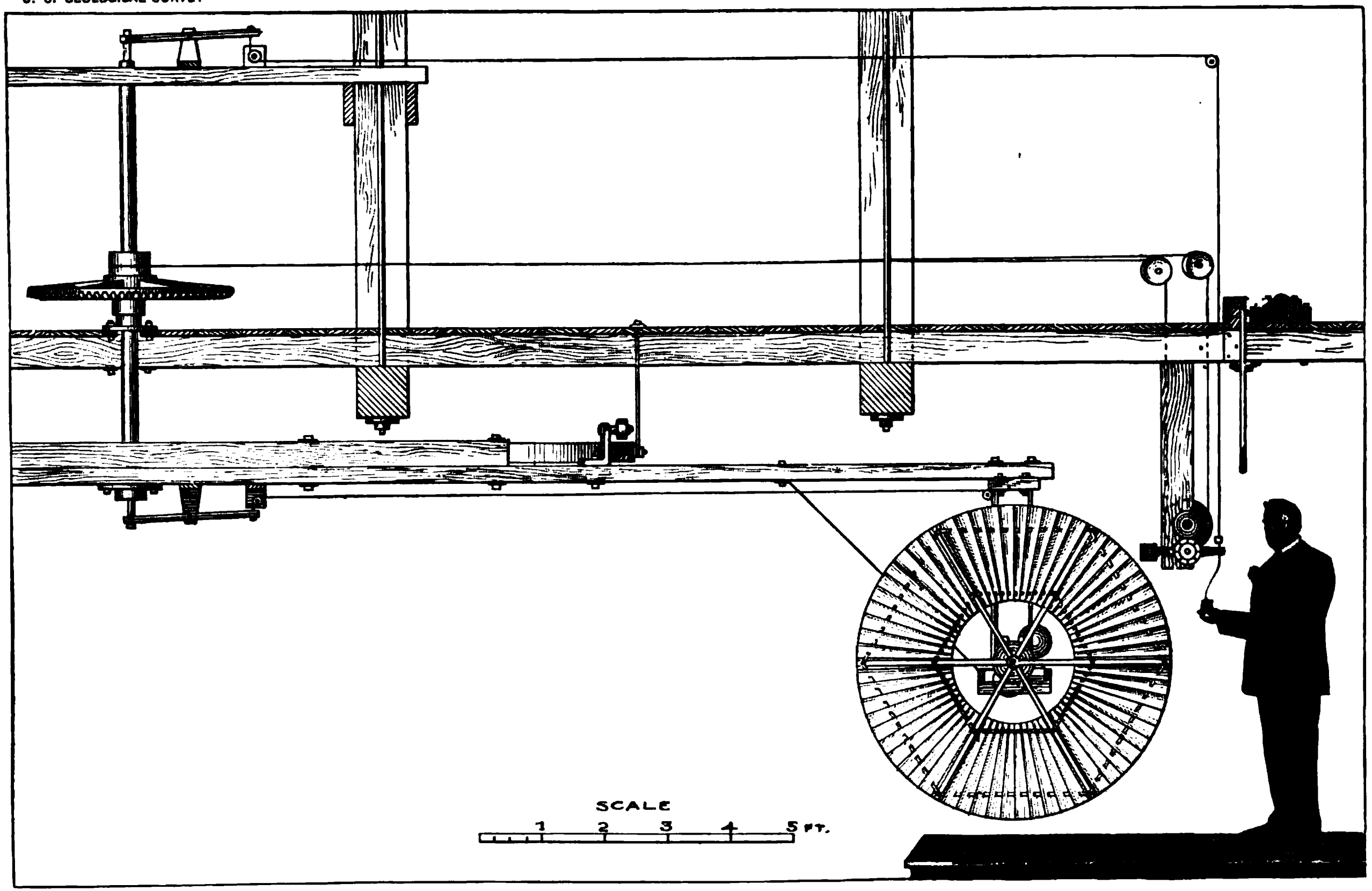
In wheel No. 3 we followed closely Smeaton's angles of weather, but did not obtain so good results as with greater angles. In fact, we were not able to obtain the best results with weather angles so small as Smeaton's in any of our wind wheels. Nor did our sail speeds, as compared with wind velocity, nearly approach the speeds obtained by Smeaton. Even our unloaded wheels did not show the sail speed attained by the best of Smeaton's wheels when loaded for maximum work.

This difference in the ratio of sail speed to wind velocity constituted the greatest disagreement between his results and ours. Our loads at the maximum of work were smaller as compared with greatest loads, and the speeds of revolution at maximum work as compared with speeds of unloaded wheels were smaller for our wheels than for Smeaton's. The general laws established by Smeaton, as enunciated in his eight "maxims," were substantially confirmed by our experiments. The law of cubes pertaining to maximum products and the law of squares pertaining to greatest loads, or starting forces, were more exactly fulfilled in our experiments than in Smeaton's. The differences in results as regards angles of weather, speeds, and best loads might have been due to differences in the construction of the wheels.

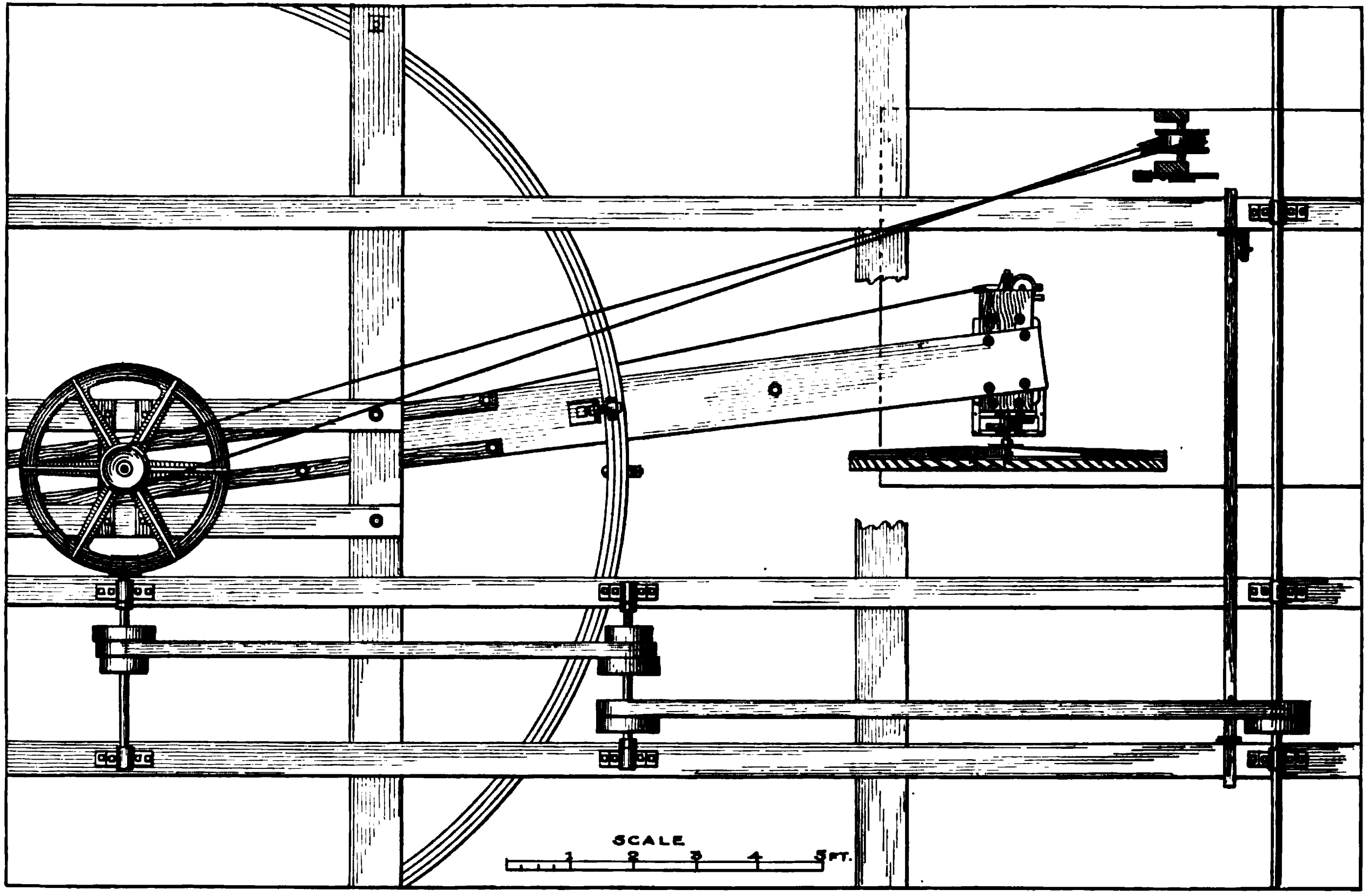
Smeaton constructed his wheels after the manner of windmill construction in his time, and we constructed our wheels mostly after the methods adopted by American manufacturers at the time we experimented. Our methods of experiment were similar, though Smeaton's experiments were conducted on a much smaller scale with smaller wheels, and his appliances generally were crude as compared with our own.

Smeaton allowed about one-eighth of his total applied load as the equivalent additional load due to friction. This friction, as Smeaton determined it, was in reality friction at starting only, and it must have been much in excess of the friction under the rapid revolutions of his wheels, and helped considerably to swell his products.

Still another allowance must be made in comparing Smeaton's efficiencies with ours, on account of the relative shortness of the sweep, which carried his wheels in a circle against still air. The velocity of the centers of his wheels was taken as the equivalent velocity of wind. As a matter of fact, some point beyond the center of the wind wheel, farther away from the axis of the sweep, should have been taken to represent wind velocity. The distance from the axis of Smeaton's



ELEVATION OF APPARATUS USED IN WHEEL TESTS.



PLAN OF APPARATUS USED IN WHEEL TESTS.

sweep to the extremity of his sail as it revolved was, when greatest, nearly double its least distance, and the energy of the wind acting on the tip of his sail was more than seven times as great at the maximum as at the minimum distance. To compute accurately the total wind energy intercepted by the wheel, after taking into account the various velocities of impingement, would be an interesting problem in integral calculus.

The differential expression for work is easily found, but the integration is not so simple. An approximate calculation shows that the wind energy intercepted by Smeaton's wheel was more than 7 per cent in excess of what it would have been had all points of the wheel met the air with the same velocity as at the center. The difference is not so large as one would expect from the great difference in energy at extreme positions. We doubt whether anything should be deducted from Smeaton's products on this account, for only a very limited portion of the sails could have a proper relative velocity with respect to the wind. Our wheels were, of course, similarly affected, although in considerably less degree.

Weisbach's theoretical formulæ for wind action, if correct, would cast a cloud over Smeaton's results; for he concludes his rather elaborate mathematical discussion with these words: "According to these experiments [Smeaton's] the action of the wind in general upon sail wheels is greater than is given either by the theory or by Coulomb's experiments." Coulomb's very incomplete experiments seem to have been a great source of consolation to those mathematicians whose theories would not permit the realization of efficiencies so great as Smeaton obtained.

Our own experience with wind wheels in actual use, in widely different lines of work, and the testimony of many persons using them, convince us that the efficiencies we obtained and which Smeaton obtained in artificial wind are not so great as those commonly obtained now in natural wind. We consider our experiments valuable principally on account of the comparisons made and the insight they afford into the causes of waste. Through the courtesy of Mr. H. N. Wade, manager of the United States Wind Engine and Pump Company, of Batavia, Illinois, we are enabled to reproduce the original records of our experiments on wind wheels as they were made in 1883.

APPARATUS.

Our experiments were conducted in a room about 36 feet wide, 48 feet long, and 19 feet high from floor to roof trusses.

Pls. VI and VII represent, in elevation and plan, as a whole, the apparatus that was used and show portions of the roof trusses underneath which the sweep was suspended. The rear end of the sweep, not shown, carried a counterweight, which caused the whole apparatus to balance on the central shaft. Two rollers carried by the sweep on

opposite sides of the suspending shaft ran lightly over a large circular track and prevented vertical oscillations. Pls. VIII and IX present enlarged views, showing the details of the dynamometer and its method of application.

These four plates and the illustrations of wind wheels Nos. 3, 6, 19, 24, 29, 39, 40, 44, 60, and 61 were recently prepared from data in our possession. The illustrations of wheels Nos. 2, 35, and 48 are reproductions of the drawings made for the original records, as are also all the other illustrative figures which are shown in connection with the original records. In computing the figures denoting efficiencies, shown in connection with the illustrations of wheels Nos. 3 and 6, axle friction was called 0.15 pound instead of the 0.3 pound given in the tables, as explained under the heading "Corrections for axle friction."

In these two cases, and also in computing the efficiency of wheel No. 2, allowance was made for temperature as recorded and for atmospheric density, according to the records of the United States Signal Service station at Chicago for 2 p. m. on the days of experiments.

The efficiencies shown in connection with all the other illustrations of wind wheels were obtained by simply multiplying the efficiency for No. 2 by the ratios of products given in the various tables where direct comparison with No. 2 is shown.

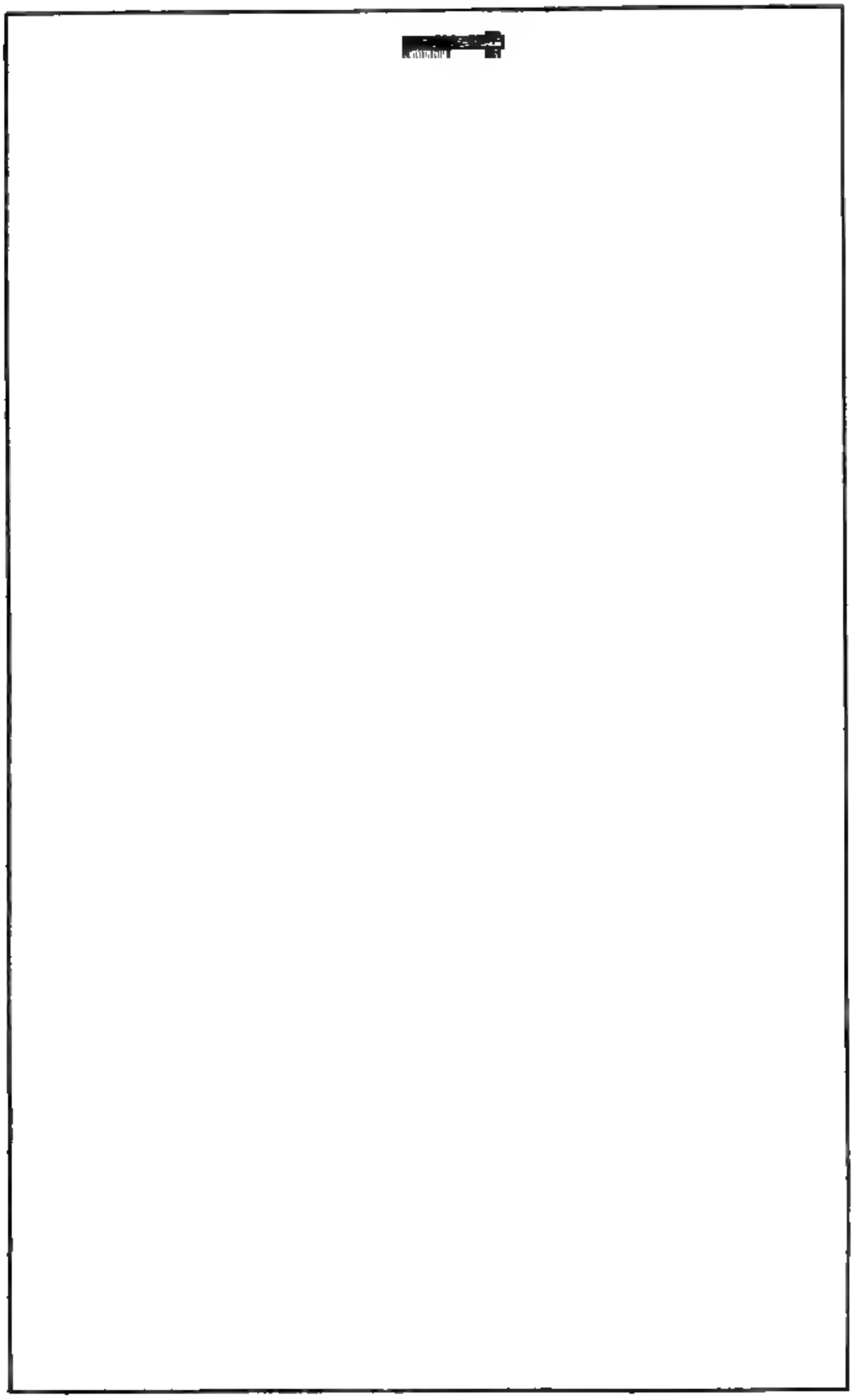
The original records of 1883, immediately following, end on page 72. The comments following page 72, including the tables on pages 74 and 77, have recently been prepared.

ANGLE OF WEATHER.

The term "angle of weather," used in connection with the following tables, means the angle made by the face of the sail with the plane of the wheel.

ARTIFICIAL WIND.

In conducting these experiments with windmills, it was necessary that results to be compared should be obtained in wind of uniform velocity. We therefore made use of artificial wind, obtained by carrying the wind wheels in a circle against still air on the end of a long sweep suspended beneath the roof trusses of a large room used for setting up tanks. The sweep was made to revolve horizontally around its vertical axis by means of gearing, pulleys, and belts connected with a line shaft driven by an 80-horsepower Reynolds–Corliss steam engine, which furnished the motive power for the works of the United States Wind Engine and Pump Company. The distance from axis of sweep to center of wind wheel was 14 feet, so that the velocity of wind against the wind wheel in miles per hour would be indicated very closely by the number of revolutions per minute made by the sweep. To attain absolute accuracy the length of sweep should have been 14.006 feet. Hence it was only necessary to note the number of turns per minute



PLAN AND ELEVATION OF DYNAMOMETER

made by the sweep in order to know the velocity of wind in miles per hour with sufficient accuracy.

For counting the number of turns of the sweep a toothed wheel, containing 80 teeth, was used, which was made to revolve at the same rate as the sweep. Thus the fractions of a turn could be easily determined to within 0.0125, and we made a practice of setting down the fractional turns to within 0.00125, thus securing relative accuracy in determining the velocity of the wind to within 0.00125 of a mile per hour.

The face of the wind wheel was set at right angles to the direction of the wind. The frame supporting the shaft of the wind wheel was suspended about 3 feet below the sweep by four iron straps, presenting their thin edges to the wind, so that the action of the wind upon the wheel should be obstructed as little as possible by the sweep or otherwise. The motion of the sweep undoubtedly carried the air of the room with it to some extent, but not so as to produce a noticeable current.

DYNAMOMETER.

The ordinary Prony friction brake was used, with such modifications and additions as circumstances demanded.

The brake consisted of two pine blocks, clamped vertically upon a brass cylinder 5¼ inches in diameter, attached to the shaft of the wind wheel. But instead of using two bolts, with thumb nuts for adjusting the brake, one bolt was used as a hinge beneath the cylinder, and the adjustment was made by means of a cord passing across from one block to the other around small iron sheaves, which turned on common wood screws fastened into the tops of the two blocks, so that the pressure of the blocks against the cylinder corresponded to about sixteen times the tension of the cord.

The adjusting cord was carried back from the brake some distance in a direction parallel to the axis of the cylinder to a sheave fixed to the frame supporting the shaft of the wind wheel. From that point the cord was carried by means of sheaves, levers, etc., up through the hollow shaft supporting the sweep and finally fastened to one end of a lever. The other end of the lever was hinged and provided with a sliding weight, by means of which the tension of the cord could be adjusted from the station of observation while the sweep was in motion. The brake was provided with a horizontal graduated arm carrying a weight, which could be moved in or out to correspond to any desired load. Suitable stops were provided, allowing a limited motion of the brake and graduated arm, which could be conveniently watched from the station of observation, just beyond the reach of the sweep. The brake and graduated arm were balanced, as regards the action both of gravity and of centrifugal force, before applying the loads, which were balanced by the friction of the brake. The thrust of the rear end of the shaft of the wind wheel was sustained by a steel point.

METHOD OF EXPERIMENT.

For noting the number of turns of the wind wheel, the rear end of the shaft was provided with a worm, with which a toothed wheel could be thrown in or out of contact at the pleasure of the operator from the station of observation. Each turn of the wind wheel would cause the toothed wheel to make 0.0125 of a revolution, as there were 80 teeth in the wheel, and the fractional turns could easily be estimated to within 0.1 of a revolution of the wind wheel. The weight on the graduated arm was always expressed in pounds and decimal parts at 1 foot from the center of shaft of the wind wheel. During use the brake was freely lubricated with machine oil.

For a trial load the weight on the graduated arm was set at some number, say 1 pound. Then the counter which was to record the speed of the wind wheel was set at 0, as was also the counter which was to record the velocity of the wind. The sweep having been set in motion, the speed of the wind wheel was checked by the brake, which was adjusted from the station of the observer by regulating the tension of the adjusting cord until the weight on the graduated arm was just lifted by the friction, and no more. As soon as the friction and weight were well balanced the counters which were to record the speed of the wheel and velocity of wind were thrown in by a single movement of a lever, and at the expiration of one minute they were both instantaneously thrown out. Then the sweep was stopped at the station of observation, the number of revolutions of the wind wheel recorded, and also the velocity of the wind.

To the load applied was added the friction of the journals, also expressed in pounds at 1 foot from the center of the shaft. This sum made the total load, which was multiplied by the number of turns of the wind wheel.

Then a second product was obtained in precisely the same manner with a greater load applied; and if greater than the first, a still greater load was applied and the corresponding product obtained. A succession of products were thus obtained corresponding to a succession of loads gradually increased until the products began to decrease on account of the diminishing speed of the wheel. The greatest product corresponded to the best load for the wheel, and the actual work performed by the wheel in each case could be obtained by multiplying the product by 6.2832 feet, equal to the circumference of the circle whose radius is 1 foot. In obtaining these products measurements were taken several times for each load and the total load was multiplied by the average turns of the wheel per minute. The average wind was also taken for record. The velocity of wind was supposed to be nearly uniform, but varied slightly with the speed of the engine, and the variation was sufficient to affect results considerably in some cases; hence the necessity of recording the velocity of the wind in each case. In comparing

END VIEWS OF DYNAMOMETER.

results some allowance also had to be made for differences in velocities of wind.

In testing the speed of the wheel unloaded the brake was removed, making the load nothing but the journal friction.

STARTING FORCES.

The determination of starting forces was attended with some difficulty. In the first place, it became necessary to define what should be considered the starting force of a wind wheel—whether it should be considered the greatest load under which the wheel would turn, or the greatest load which the wheel would balance without turning. It was also necessary to decide what motion of the wheel should be defined as turning. The wheel with a certain load would sometimes perform one revolution in ten or twenty minutes, if that could be called turning; between that and proper continuous turning there were many gradations. It was impracticable to decide when the wheel reached the lowest limit of speed which could properly be called turning. Therefore we have considered the starting force as the greatest load the wheel would balance without turning. Our method of determining starting forces was to clamp the brake so tightly on the cylinder that the wheel could not turn, but could lift the load applied such small distance as was allowed by the stops which limited the motion of the brake. The sweep was then set in motion and timed for one minute, during which time the load on the graduated arm was watched, its alternating upward and downward movements were noted, and judgment was exercised as to the balance between the load applied and the starting force of the wind wheel. The average velocity of wind during these tests was always recorded after March 13, 1883, but not always before that date.

In lifting the load the starting friction of the journals was also overcome by the wind wheel, but when the weight descended the load overcame the starting friction of journals in addition to the starting force of wind, and as the load almost constantly moved up and down when well balanced, nothing should be added to loads applied for friction in case of starting forces. Yet the friction has been added in the tables, the same as to other loads applied, in order to accommodate the statements at the head of columns for loads. On account of the starting friction being great and uncertain, and for other reasons, the starting forces recorded prior to March 13, 1883, are not so much to be relied upon as those recorded after that date; nor were the later tests for starting forces nearly so accurate as those for products.

JOURNAL FRICTION.

For journal friction previous to March 13, 1883, see description in connection with wind wheel No. 11, page 38. After the date above given the journal friction was greatly reduced by the use of large anti-

friction wheels in place of the front box, just behind the wind wheel and in front of cylinder, where the weight of the wind wheel and cylinder was mostly supported. In place of the rear box a small steel pin was inserted in the end of the shaft and turned in a brass box. The end thrust of the shaft, due to wind pressure and tension of the adjusting cord, was sustained by a steel point, as before.

As thus improved, one-half an ounce hung to a thread wound around the outside of wheel No. 37 overcame friction at very slow motion, and was almost if not quite equal to starting friction. The brake was removed during this test.

Let x = weight 12 inches from axis required to overcome friction.
30 inches = distance from axis to thread.
$\frac{1}{2}$ ounce = $\frac{1}{32}$ pound.

$$12\,x = \frac{30}{32}$$

$$x = 0.0785 = \text{friction at very slow motion or at starting.}$$

With brake and wind wheel removed 26.50 ounces hung by a thread wound around the forward end of shaft 0.7969 inch in diameter overcame friction at very slow motion and was almost equal to starting friction, and 24.25 ounces hung in the same way overcame friction at 50 turns per minute, and would not overcome friction when speed was much less. 0.8125 inch = diameter outside of thread, 0.4024 inch = radius to center of thread.

Friction at 50 turns per minute is to starting friction as 24.25 is to 26.50. Hence, $0.0785 \times \frac{24.25}{26.50} = 0.0714$ pound = journal friction at 50 turns per minute, with wind wheel on and brake removed. The weight of the brake would, of course, add a little to the friction, which we have uniformly called 0.1 in the tables, as explained on page 28, under the table.

The 0.3-pound friction added to loads applied prior to March 13, 1883, was friction at very slow motion and was undoubtedly much in excess of friction at speed of wheels corresponding to maximum products, as is evinced by the fact that notwithstanding the great reduction of starting friction the tables do not show for the same applied loads, or even unloaded, very much increase of speed of wheels after March 13, 1883, over speeds indicated previous to that date. If 0.1 pound had been added to applied loads previous to March 13, 1883, the products at maximum and for higher speeds of wheels would probably have been more nearly correct. It was this uncertainty and ignorance regarding friction at different speeds that led us to reduce as much as possible this source of error. However, the error thus arising does not greatly affect comparative values of products recorded prior to March 13, 1883, although products affected by allowance of 0.3 pound for friction should not, unless corrected, be compared with products recorded after above date.

COMPARATIVE STANDARD WHEEL.

In the earlier stages of these experiments we acted on the supposition that only such variations in the state of the atmosphere as were indicated by the barometer and thermometer should affect the work performed by a wheel tested at different times in wind of the same velocity. But later we were convinced that the readings of the barometer and thermometer would not always account for variations in products given by the same wheel on different days. We were also convinced of the uselessness of speculating as to, or trying to understand and forestall, all the causes that might combine to affect results. Therefore we adopted the practice of comparing the maximum product of each wheel tested with the maximum product of wheel No. 2, obtained in close proximity as to time and under similar conditions in all respects. This could be done with a good deal of certainty, and no further trouble was experienced on account of contradictory results. After the best loads had been ascertained by trial, comparative tests were made by trying first one wheel and then the other in succession until a considerable number of measurements had been taken. Then as many measurements as possible, giving the same average velocity of wind for both wheels, were selected from each set of experiments.

In this way the product obtained was usually the average of 8 to 10 measurements of each wheel made under the same conditions of time, wind, weather, and whatever else might affect the results. The product of No. 2 was thus used as a standard of measure, and the ratio of products indicated the relative value of the wheel compared.

For further particulars consult tables of experiments of later date than March 13, 1883.

Results of experiments performed in March and May, 1883, with wheel No. 2.

Velocity of wind per hour.	Load applied + 0.1 for friction.	Turns of wheel per minute.	Product at maximum.	Thermometer.	Date.
Miles.	*Pounds.*			°*F.*	1883.
6.437	0.1	43.78	.....	62	May 14
6.371	1.1	23.90	26.290	54	May 14
6.381	2.4	0	.....	62	May 14
8.417	.1	59.05	.....	53	Mar. 14
8.403	1.9	32.875	62.463	50	Mar. 14
8.405	4.2	0	.....	53	Mar. 14
10.898	.1	77.85	.....	46	May 21
11.041	3.3	41.06	135.498	60	May 17
10.976	6.9	0	.....	46	May 21

Previous to making the above experiments, March 13, 1883, the dynamometer was improved by the addition of an automatic brake adjuster

and antifriction wheels, which reduced starting friction from about 0.3 to about 0.08 pound, and made journal friction at 50 turns per minute about 0.071 pound. In the table friction was called 0.1 pound for convenience, as the absolute friction in each case could not easily be obtained, and the error does not materially affect comparative results. (See pages 25 and 26 for "Journal friction.")

Average products of wheel No. 2, which was used as a standard for comparison, were obtained by selecting from numerous tests several numbers—generally 8 to 10—which corresponded to wind of the same average velocity as wind for wheels compared in each case; the difference of averages in no case exceeded 0.001 mile per hour in the table on page 47.

Measurements for maximum products of two wheels compared were always taken as far as possible under the same conditions of wind, temperature, barometer, weather, time, etc.

RESULTS OF ORIGINAL TESTS.

TABLES AND DESCRIPTIONS OF WIND WHEELS.

WHEEL NO. 1.—*Results of experiments.*

Velocity of wind per hour.	Load applied +0.3 for friction.	Turns of wheel per minute.	Product.
Miles.	*Pounds.*		
8.427	0.3	59.08	17.724
8.431	1.2	42.60	51.120
8.385	1.4	39.90	55.860
8.412	1.6	35.69	57.104
8.452	1.8	31.69	57.042
8.432	2.0	28.02	56.040
.....	2.85	0	0

Experiments made June 1 and 2, 1882.
Load expressed in pounds applied 1 foot from center of wheel.
Circumference of circle whose radius is 1 foot, 6.2832 feet.
Work per minute at the maximum, $57.104 \times 6.283 = 358.784$ foot-pounds
Diameter of wheel, 5 feet.
Number of slats or sails, 30.
Length of slats, 18 inches.
Width of slat at outer end, 3.56 inches.
Width of slat at inner end, 1.344 inches.
Total area of slats or sails, 9.19 square feet.
Angle of weather, 35 degrees.
Portion of available annular space filled by sails, 0.5.
The spaces between are equal to the spaces occupied by the slats. This wheel is the same as No. 2 with one-half the slats omitted.
Slats, plain surfaces, made of white pine three-sixteenths of an inch thick, with forward edges trimmed to an edge.

WHEEL NO. 2.—*Results of experiments.*

Velocity of wind per hour.	Load applied + 0.3 for friction.	Turns of wheel per minute.	Product.	Thermometer.	Date.
Miles.	*Pounds.*			° *F.*	1882.
8.411	0.3	57.95	17.385	69	.....
8.381	0.9	49.00	44.100	.....	.....
8.451	1.05	47.00	49.350	.....	.....
8.435	1.3	43.08	56.004	77	June 7
8.445	1.5	40.80	61.200	73	June 7
8.412	1.7	37.30	63.410	70	June 7
8.460	1.8	35.85	64.530	78	.....
8.436	1.9	34.89	66.291	72	June 8
8.429	2.0	33.43	66.860	78	.....
8.443	2.1	31.33	65.793	69	June 8
8.421	2.3	27.60	63.480	73	June 8
8.446	2.5	24.48	61.200	75	June 8
8.416	2.7	21.70	58.590	76	June 8
8.398	2.9	20.00	58.000	.....	.....
8.338	3.1	15.80	48.980	.....	.....
.....	3.81	0	0	.....	June 9

Total area of slat sails 18.380 square feet.

Angle of weather, 35 degrees.

The same as No. 1, with double the number of slats—that is, the projections of the slats upon the plane of the wheel equaled the entire available annular area. An area as shown in fig. 8 at each of the six arms constituted the space not available. Slats held in place by 12 straight notched pieces extending from arm to arm the same as in No. 1.

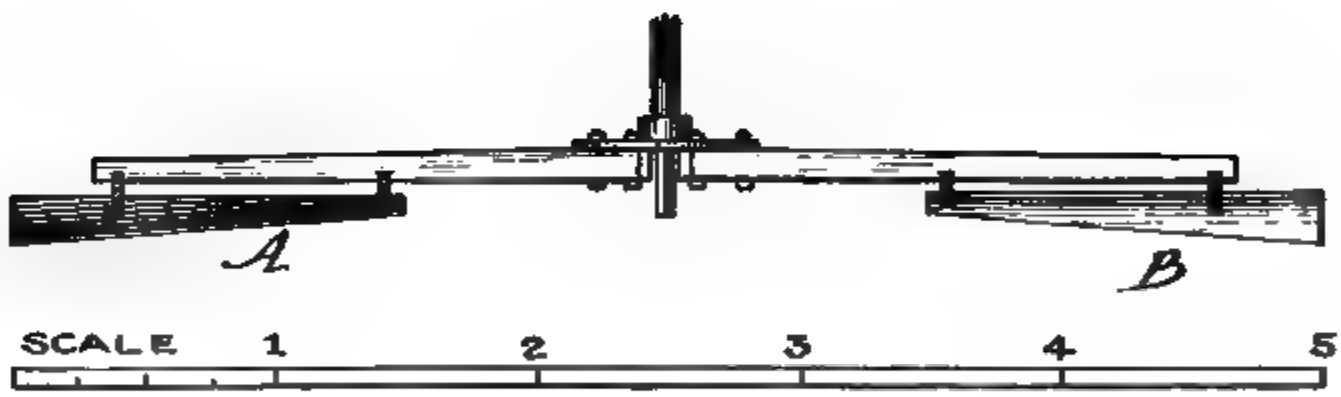


FIG. 7.—Elevation and section of wheel No. 2. (Sail area, 18.280 square feet; efficiency, 0.154.)

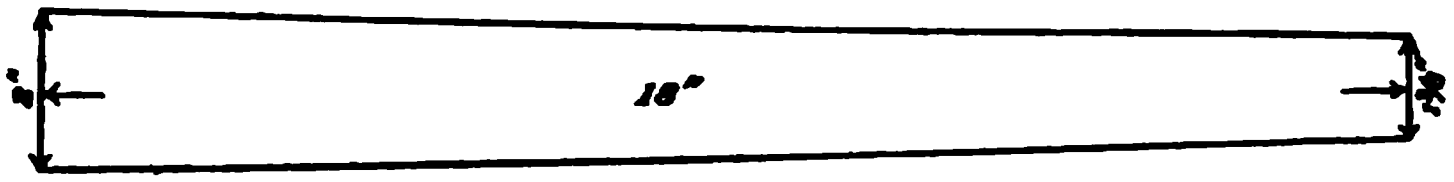


FIG. 8.—Outline of area not available.

WHEEL NO. 3.—*Results of experiments.*

Velocity of wind per hour.	Loads applied+0.3 for friction.	Turns of wheel per minute.	Product.	Thermometer.	Date.
Miles.	*Pounds.*			° *F.*	1882.
8.476	0.3	90.48	27.144	68	June 22
8.435	.95	69.40	65.930	68	June 22
8.441	1.05	64.90	68.145	68	June 21
8.428	1.1	62.15	68.365	88	June 22
8.447	1.2	59.65	71.580	69	June 19
8.436	1.3	55.36	71.968	83	June 22
8.402	1.4	51.10	71.540	69	June 21
8.423	1.5	47.48	71.220	74	June 19 June 22
8.441	1.7	41.00	69.700	71	June 22
8.404	1.9	32.00	60.800	71	June 22
.....	2.4	0	0	.....	June 22

FIG. 9.—Elevation and section of wheel No. 3. (Sail area, 13.590 square feet; efficiency, 0.161.)

Diameter of wheel, 5 feet.

Number of sails, 12.

Sails of lineal dimensions as shown in figs. 10 and 11, made of white-pine boards three-sixteenths of an inch thick and fastened by hinges near each end to 12 pine bands bent to arcs of circle and secured to the 6 arms.

Total sail surface, 13.59 square feet.

Sails concave toward the wind.

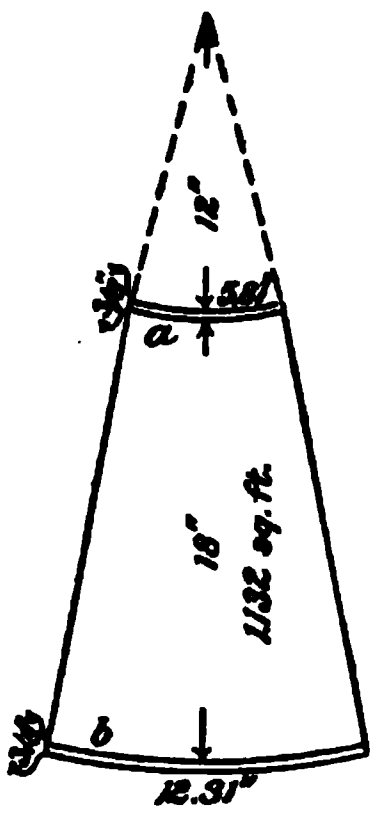


FIG. 10.—Dimensions of sails of wheel No. 3. 18 inches is the extreme length of sail.

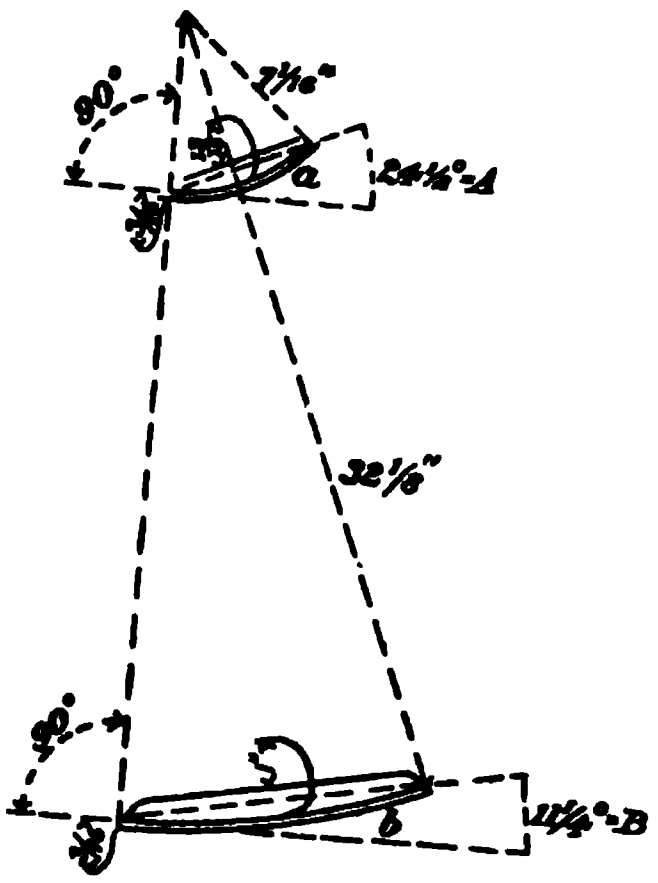


FIG. 11.—Angles of weather of sails of wheel No. 3. *A*, Angle of weather at inner ends of sails; *B*, Angle of weather at outer ends of sails.

WHEEL NO. 4.—*Results of experiments.*

Velocity of wind per hour.	Load applied + 0.3 for friction.	Turns of wheel per minute.	Product.	Thermometer.	Date.
Miles.	*Pounds.*			° *F.*	1882.
8.354	0.3	89.43	26.829	76	June 29
8.372	0.9	74.54	67.086	76	June 29
8.375	1.1	70.03	77.033	76	June 29
8.324	1.3	62.75	81.575	68	June 29
8.461	1.5	60.72	91.080	73	June 28
8.467	1.7	55.93	95.081	73	June 28
8.465	1.9	48.75	92.625	73	June 28
8.366	2.1	42.78	89.838	68	June 29
8.386	2.3	38.50	88.550	68	June 29
8.369	2.5	29.13	72.825	68	June 29
.....	3.3	0	0	.....	June 29

Wheel the same as No. 3, except that the inclination of the sails was changed, making the angle of weather 20 degrees at outer ends of sails and 30 degrees at inner ends of sails.

WHEEL NO. 5.—*Results of experiments.* (*a*)

Velocity of wind per hour.	Loads applied +0.3 for friction.	Turns of wheel per minute.	Product.	Thermometer.	Date.
Miles.	*Pounds.*			°*F.*	1882.
8.444	0.3	86.78	26.034	74	July 12
8.499	0.9	73.56	66.204	74	July 12
8.479	1.1	68.72	75.592	74	July 12
8.493	1.3	64.18	83.434	71	July 5
8.419	1.5	57.98	86.970	71	July 5
8.422	1.7	53.86	91.562	71	July 5
8.468	1.9	50.83	96.577	71	July 5
8.465	2.1	46.10	96.810	74	July 5
8.456	2.3	41.60	95.680	74	July 5
8.414	2.5	33.86	84.650	63	July 6
8.424	2.7	27.70	74.790	63	July 12
8.440	2.9	19.62	56.898	63	July 12
.....	3.7	0	0	.....	July 5
8.491	1.9	51.88	98.572	71	.....

a See wheel No. 44, p. 57.

Wheel the same as No. 3, except that the inclination of the sails was changed, making the angle of weather 22.5 degrees at outer ends of sails and 32.5 degrees at inner ends of sails.

WHEEL NO. 6.—*Results of experiments.*

Velocity of wind per hour.	Load applied + 0.3 for friction.	Turns of wheel per minute.	Product.	Thermometer.	Date.
Miles.	*Pounds.*			°*F.*	1882.
8.373	0.3	69.03	20.709	32	Dec. 9
8.355	1.5	47.30	70.950	34	Dec. 9
8.348	1.7	44.00	74.800	34	Dec. 9
8.405	1.8	42.10	75.780	35	Dec. 9
8.317	1.9	38.28	72.732	35	Dec. 9
a 8.368	1.3	50.83	66.079	38	Dec. 9
.....	3.4	0	0	33	Dec. 8

a When reversed, so as to present its back side to the wind.

FIG. 12.—Elevation and section of wheel No. 6. (Sail area, 10.668 square feet; efficiency, 0.163.)

Diameter of wheel, 5 feet.

Arms and bands the same as in wheel No. 3.

Number of sails, 24. Sails of lineal dimensions as in fig. 13; made of white-pine boards three-sixteenths of an inch thick, and hinged to the bands as in No. 3.

Sails plain, with forward edges trimmed to an edge.

Total sail surface, 10.668 square feet.

Angle of weather, 30 degrees.

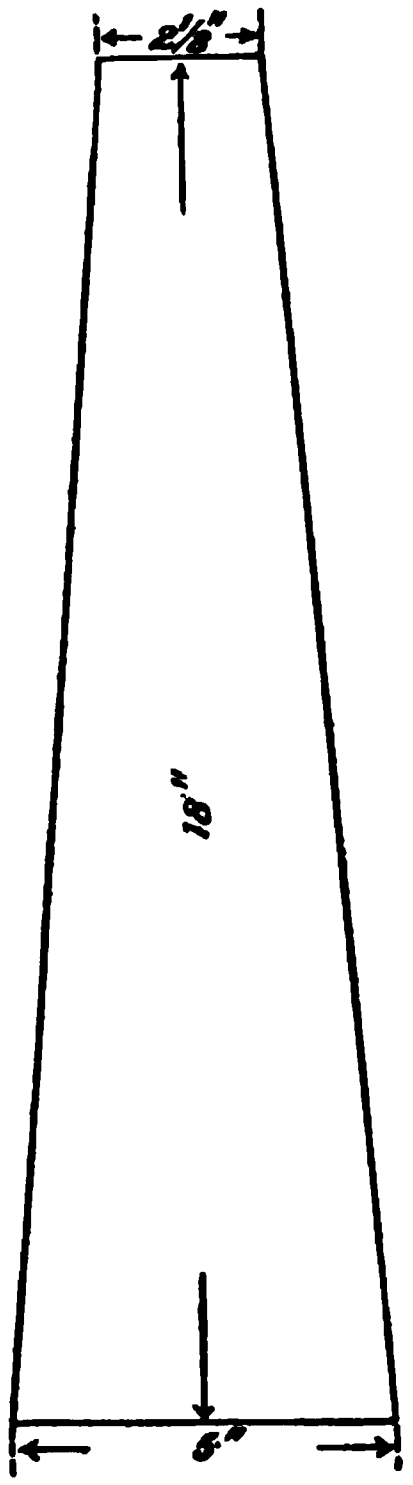


FIG. 13.—Dimensions of sails of wheel No. 6.

WHEEL NO. 7.—*Results of experiments.*

Velocity of wind per hour.	Loads applied + 0.3 for friction.	Turns of wheel per minute.	Product.	Thermometer.	Date.
Miles.	*Pounds.*			°*F.*	1882.
8.361	0.3	73.60	22.080	42	Dec. 12
8.380	1.3	52.50	68.250	39	Dec. 12
8.416	1.5	47.40	71.100	40	Dec. 11
8.359	1.7	40.74	69.258	40	Dec. 12
.....	2.8	0	0	42	Dec. 12

Wheel the same as No. 6, except that the inclination of the sails was changed, making the angle of weather 25 degrees.

WHEEL NO. 8.—*Results of experiments.*

Velocity of wind per hour.	Loads applied + 0.3 for friction.	Turns of wheel per minute.	Product.	Thermometer.
Miles.	*Pounds.*			°*F.*
8.333	0.3	62.67	18.801	.....
8.344	1.3	46.83	60.879	48
8.403	1.5	44.23	66.345	48
8.375	1.7	40.23	68.391	39
8.366	1.9	36.84	69.996	41
8.368	2.1	32.80	68.880	47
8.354	2.3	27.70	63.710	47
.....	3.55	0	0	.....

Experiments made December 13, 1882.

Wheel the same as No 6, except that the inclination of the sails was changed, making the angle of weather 35 degrees.

WHEEL NO. 9—*Results of experiments.*

Velocity of wind per hour.	Loads applied + 0.3 for friction.	Turns of wheel per minute.	Product.	Thermometer.
Miles.	*Pounds.*			°*F.*
8.374	0.3	66.40	19.920	43
8.361	1.3	49.73	64.649	38
8.375	1.5	47.15	70.725	39
8.350	1.7	42.30	71.910	40
8.364	1.9	38.20	72.580	40
8.344	2.1	34.58	72.618	42
8.323	2.3	30.70	70.610	42
.....	3.4	0	0	.....

Experiments made December 14, 1882.

Wheel the same as No. 6, except that the inclination of the sails was changed, making the angle of weather 32.5 degrees.

WHEEL NO. 10.—*Results of experiments.*

Velocity of wind per hour.	Loads applied + 0.3 for friction.	Turns of wheel per minute.	Product.	Thermometer.	Date.
Miles.	*Pounds.*			°F.	1882.
8.347	0.3	72.23	21.690	34	Dec. 15
8.336	1.1	54.77	60.247	45	Dec. 14
8.329	1.3	53.30	69.290	45	Dec. 14
8.345	1.5	48.70	73.050	33	Dec. 15
8.358	1.7	43.78	74.426	34	.....
8.338	1.9	39.33	74.727	35	.....
8.351	2.1	35.06	73.626	39	.....
.....	3.25	0	0	.....	.....

Wheel the same as No. 6, except that the inclination of the sails was changed, making the angle of weather 27.5 degrees.

WHEEL NO. 11.—*Results of experiments.*

Velocity of wind per hour.	Loads applied + 0.3 for friction.	Turns of wheel per minute.	Product.	Thermometer.
Miles.	*Pounds.*			°F.
8.415	0.3	77.60	23.280	41
8.353	1.3	51.64	67.132	39
8.391	1.5	45.46	68.190	40
8.401	1.7	39.52	67.184	40
8.410	1.9	*a* 33.14	62.966	41
.....	2.1	(*b*)	.....	.....
.....	2.3	0	0	.....

a Started slowly and with difficulty, though well balanced. Once needed help to start.
b Ran slowly two or three minutes and stopped.

Experiments made December 18, 1882.

Wheel the same as No. 6, except that the inclination of the sails was changed, making the angle of weather 20 degrees.

A journal friction test made with wheel No. 11 by hanging a 1¾-ounce weight by a thread wound around the outside of the wheel showed that this weight did not overcome starting friction, but was sufficient to accelerate motion after the wheel was started at moderate speed.

Let x = journal friction, at 1 foot (12 inches) from axis.
30 inches = distance of 1¾-ounce weight from axis.

$1.75 \times 30 = 12\,x$.

$x = 4.375$ ounces $= 0.2734$ pound = friction of journals at moderate speed.

The journal friction diminishes somewhat with the increase of speed, although authorities give the same coefficient of friction at all speeds. Some variation in journal friction is also due to difference in weights of wheels and in lubrication; and as the above test was made with the brake removed, we have considered it approximately correct to call journal friction = 0.3 pound in all cases. See, however, later conclusions.

WHEEL NO. 12.—*Results of experiments.*

Velocity of wind per hour.	Load applied + 0.3 for friction.	Turns of wheel per minute.	Product.	Thermometer.
Miles.	*Pounds.*			° *F.*
8.405	0.3	75.60	22.680	44
8.385	.95	56.18	53.371	40
8.376	1.1	50.78	55.858	40
8.341	1.3	*a* 43.88	57.044	41
8.376	1.5	*b* 35.42	53.130	42
.....	1.6	(*c*)	.....	.....
.....	1.7	0	0	.....

a Started slowly.

b Needed assistance to start in every instance, though without assistance it would barely move, at the rate, perhaps, of one turn in ten minutes.

c Ran three minutes and stopped, after having been started at moderate speed.

Experiments made December 19, 1882.

Wheel the same as No. 6, except that the inclination of the sails was changed, making the angle of weather 15 degrees.

WHEEL NO. 13.—*Results of experiments.*

Velocity of wind per hour.	Load applied + 0.3 for friction.	Turns of wheel per minute.	Product.	Thermometer.	Date.
Miles.	*Pounds.*			° *F.*	1882.
8.369	0.3	56.33	16.899	45	Dec. 20
8.377	1.7	37.13	63.121	45	Dec. 19
8.353	1.9	34.10	64.790	43	Dec. 20
8.352	2.1	31.30	65.730	41	Dec. 20
8.407	2.3	28.70	66.010	42	Dec. 20
8.375	2.5	25.38	63.450	42	Dec. 20
8.328	2.7	20.63	55.701	44	Dec. 20
8.351	2.9	17.25	50.025	46	Dec. 20
.....	3.1	(*a*)	.....	.....	Dec. 20
.....	3.2	(*b*)	.....	.....	Dec. 20
.....	3.7	0	0	.....	Dec. 20

a Ran very slowly after starting, and stopped several times.

b Stopped and started occasionally.

Wheel the same as No. 6, except that the inclination of the sails was changed, making the angle of weather 40 degrees.

WHEEL NO. 14.—*Results of experiments.*

Velocity of wind per hour.	Load applied + 0.3 for friction.	Turns of wheel per minute.	Product.	Thermometer.
Miles.	*Pounds.*			° *F.*
8.327	0.3	48.60	14.580	47
8.335	1.5	33.60	50.400	46
8.375	1.7	32.68	55.556	46
8.393	1.9	29.88	56.772	47
8.336	2.1	26.95	56.595	46
8.364	2.3	24.72	56.856	46
8.427	2.5	21.82	54.550	46
8.381	2.7	17.98	48.546	46
8.409	2.9	15.10	43.790	46
8.349	3.1	12.47	38.657	46
.....	3.3	(*a*)	.....	.....
.....	3.8	0	0	.....

a Ran a minute or two, stopped, and afterwards started slightly.

Experiments made December 21, 1882.

Wheel the same as No. 6, except that the inclination of the sails was changed, making the angle of weather 45 degrees.

WHEEL NO. 15.—*Results of experiments.*

Velocity of wind per hour.	Load applied +0.3 for friction.	Turns of wheel per minute.	Product.	Thermometer.
Miles.	*Pounds.*			° *F.*
8.444	0.3	46.84	14.052	30
8.402	1.7	29.36	49.912	28
8.429	1.9	27.40	52.600	30
8.479	2.1	25.30	53.130	31
8.457	2.3	22.92	52.716	33
8.443	2.5	20.17	50.425	32
8.440	2.7	17.71	47.817	33
8.438	3.1	10.20	31.620	35
.....	3.3	(*a*)	.....	30
.....	3.5	(*b*)	.....	30
8.406	3.95	0	0	35

a Turned very slowly and irregularly. *b* Barely moved.

Experiments made January 5 and 6, 1883.

Wheel the same as No. 6, except that the inclination of the sails was changed, making the angle of weather 47.5 degrees.

WHEEL NO. 16.—*Results of experiments.*

Velocity of wind per hour.	Load applied + 0.3 for friction.	Turns of wheel per minute.	Product.	Thermometer.
Miles.	*Pounds.*			° *F.*
8.443	0.3	42.40	12.720	32
8.444	1.7	27.75	47.175	32
8.440	1.9	24.92	47.348	30
8.385	2.1	23.27	48.867	30.5
8.447	2.3	20.67	47.514	38
8.419	2.5	18.45	46.125	37
8.505	2.7	16.23	43.821	37
8.426	2.9	*a* 12.33	35.757	37
8.484	3.1	(*b*)	.....	36
.....	3.3	(*c*)	.....	36
8.257	3.55	0	0	35
8.426	3.9	0	0	36

a Almost needed help to start, and once stopped within one minute.
b Stopped after running one minute.
c Stopped after running very slowly a short time.

Experiments made January 6 and 8, 1883.

Wheel the same as No. 6, except that the inclination of the sails was changed, making the angle of weather 50 degrees.

Comparative results with plain sails.

A	B	C	D	E	F	G	H	I
No. of wheel.	Angle of weather.	Velocity of wind per hour at maximum.	Greatest load.	Load at maximum.	Turns of wheel per minute at maximum.	Turns of wheel per minute unloaded.	Products at maximum work, E × F.	Total sail surface.
	°	*Miles.*	*Pounds.*	*Pounds.*				*Sq. ft.*
1	35	8.412	2.85	1.6	35.69	59.08	57.104	9.190
2	35	8.429	3.81	2.0	33.43	57.95	66.860	18.380
12	15	8.341	1.7	1.3	43.88	75.60	57.044	10.688
11	20	8.391	2.3	1.5	45.46	77.60	68.190	10.688
7	25	8.416	2.8	1.5	47.40	73.60	71.100	10.688
10	27.5	8.358	3.25	1.7	43.78	72.23	74.426	10.688
6	30	8.348	3.4	1.7	44.00	69.03	74.800	10.688
9	32.5	8.364	3.4	1.9	38.20	66.40	72.580	10.688
8	35	8.366	3.55	1.9	36.84	62.67	69.996	10.688
13	40	8.352	3.7	2.1	31.30	56.33	65.730	10.688
14	45	8.336	3.8	2.1	26.95	48.60	56.595	10.688
15	47.5	8.479	3.95	2.1	25.30	46.84	53.130	10.688
16	50	8.385	3.9	2.1	23.27	42.40	48.867	10.688

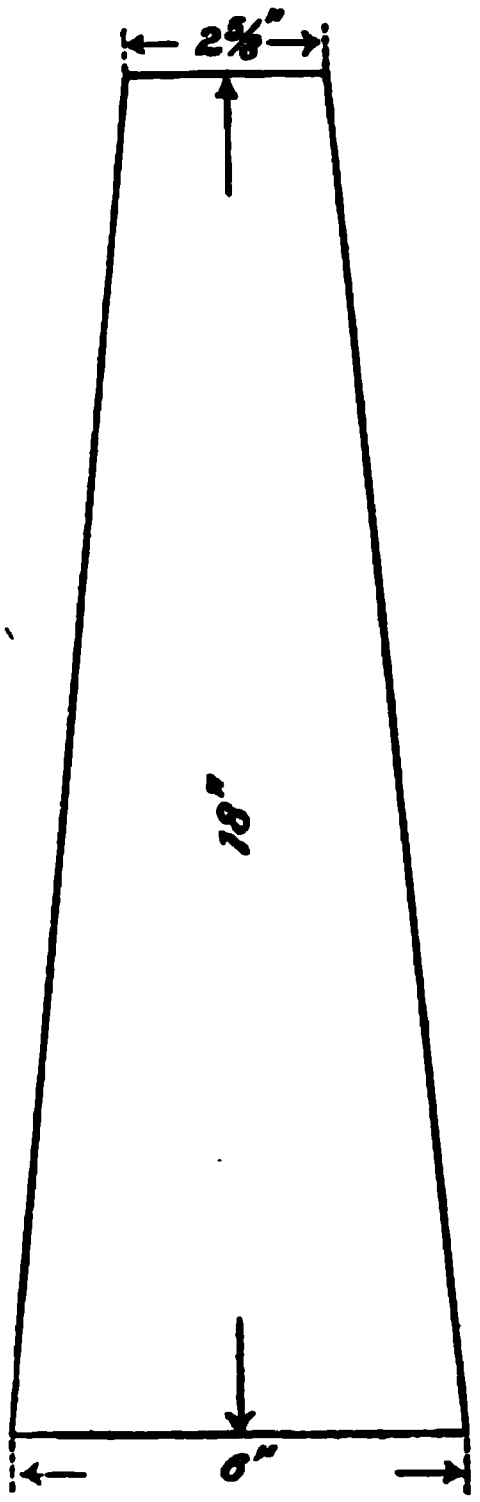


FIG. 14.—Dimensions of sails of wheel No. 18.

WHEEL NO. 19.—*Results of experiments.* (*a*)

Velocity of wind per hour.	Load applied +0.3 for friction.	Turns of wheel per minute.	Product.	Thermometer.
Miles.	*Pounds.*			° *F.*
8.375	0.3	72.26	21.678	33
8.375	1.3	53.78	69.914	34
8.466	1.5	50.32	75.480	28
8.475	1.7	47.17	80.189	28
8.379	1.9	44.48	84.512	29
8.422	2.1	42.10	88.410	30
8.439	2.3	38.20	87.860	31
8.400	2.5	32.95	82.375	31
8.397	2.7	26.98	72.846	31
8.392	2.9	22.03	63.887	32
8.370	3.1	*b* 16.03	49.693	32
8.329	3.6	0	0	32

a See table on page 47. *b* Needed assistance to start.

FIG. 15.—Elevation and section of wheel No. 19. (Sail area, 12.937 square feet; efficiency, 8.185).

Experiments made January 18, 1883.

Wheel the same as No. 18, except that the inclination of the sails was changed, making the angle of weather 27.5 degrees.

FIG. 16.—Elevation and section of wheel No. 24. (Sail area, 15.000 square feet; efficiency, 0.187).

Wheels Nos. 24 to 28 differed from each other only in angles of weather, each having 24 plain sails 18 inches long, 7 inches wide at outer ends, and 3 inches wide at inner ends. Wheels otherwise the same as No. 6.

Total area of sail surface, 15.000 square feet.

WHEELS NOS. 29 TO 33.—*Results of experiments.*

No. of wheel.	Angle of weather-er.	Velocity of wind per hour.	Load applied +0.1 for friction.	Turns of wheel per minute.	Product at maximum.	Product of No. 2 at maximum.	Ratio of products.	Date.
	°	*Miles.*	*Pounds.*					1883.
33	25	8.434	0.1	75.46	.....	.....	.....	Mar. 14
33	25	8.401	1.9	37.80	71.820	*a*62.463—	1.150	Mar. 14
33	25	8.341	3.5	0	.....	.....	.....	Mar. 14
29	27.5	8.421	0.1	73.10	.....	.....	.....	Mar. 27
29	27.5	8.406	1.9	39.10	74.290	*b*61.845—	1.201	Mar. 27
29	27.5	8.454	3.7	0	.....	.....	.....	Mar. 27
30	30	8.348	0.1	69.18	.....	.....	.....	Mar. 29
30	30	8.429	2.1	35.15	73.815	*c*62.478+	1.181	Mar. 28
30	30	8.399	4.0	0	.....	.....	.....	Mar. 28
31	32.5	8.407	0.1	66.73	.....	.....	.....	Mar. 30
31	32.5	8.418	2.1	34.94	73.374	*d*61.864—	1.186	Mar. 30
31	32.5	8.422	4.1	0	.....	.....	.....	Mar. 30
32	35	8.410	0.1	62.90	.....	.....	.....	Mar. 31
32	35	8.454	2.1	33.43	70.203	*e*61.408+	1.143	Mar. 31
32	35	8.444	4.3	0	.....	.....	.....	Mar. 31

a Wind, 8.403 miles per hour.
b Wind, 8.410 miles per hour.
c Wind, 8.427 miles per hour.
d Wind, 8.419 miles per hour.
e Wind, 8.446 miles per hour.

FIG. 17.—Elevation and section of wheel No. 29. (Sail area, 17.016 square feet; efficiency, 0.185.)

Wheels Nos. 29 to 33 differed from each other only in angles of weather, each having 24 plain sails 18 inches long, $8\frac{1}{16}$ inches wide at outer ends, and $3\frac{9}{16}$ inches wide at inner ends.

Total area of sail surface, 17.016 square feet.

Wheels otherwise the same as No. 6.

Dynamometer improved by addition of antifriction wheels and automatic brake adjuster, first used March 13, 1883, with wheel No. 33.

WHEELS NOS. 19, 20, AND 34.—*Results of experiments.*

No. of wheel.	Angle of weather.	Velocity of wind per hour.	Load applied +0.1 for friction.	Turns of wheel per minute.	Product at maximum.	Product of No. 2 at maximum.	Ratio of products.	Date.
	°	*Miles.*	*Pounds.*					1883.
19	27.5	8.471	0.1	74.94	.....	.....	.....	Apr. 12
19	27.5	8.500	1.9	39.57	75.183	*a* 62.719+	1.204	Apr. 11
19	27.5	8.455	3.3	0	.....	.....	.....	Apr. 11
20	30	8.464	0.1	70.78	.....	.....	.....	Apr. 14
20	30	8.486	1.9	39.87	75.753	*b* 62.966—	1.203	Apr. 13
20	30	8.475	3.55	0	.....	.....	.....	Apr. 14
34	25, 35	8.498	0.1	76.47	.....	.....	.....	Apr. 19
34	25, 35	8.502	1.7	43.77	74.409	*c* 61.655+	1.207	Apr. 18
34	25, 35	8.487	3.5	0	.....	.....	.....	Apr. 19

a Wind, 8.499 miles per hour. *b* Wind, 8.487 miles per hour. *c* Wind, 8.501 miles per hour.

Wheels Nos. 19, 20, and 34 differed from No. 18 only in angles of weather.

The sails of No. 34 were twisted, making angles of weather 25 degrees at outer ends of sails and 35 degrees at inner ends.

WHEELS NOS. 35 TO 38.—*Results of experiments.*

No. of wheel.	Angle of weather.	Velocity of wind per hour.	Load applied +0.1 for friction.	Turns of wheel per minute.	Product at maximum.	Product of No. 2 at maximum.	Ratio of products.	Date.
	°	*Miles.*	*Pounds.*					1883.
38	22.5	8.524	0.1	84.65	.....	.....	.....	Apr. 28
38	22.5	8.488	1.5	52.51	78.765	*a* 63.802=	1.235	Apr. 28
38	22.5	8.521	2.9	0	.....	.....	.....	Apr. 28
36	25	8.525	0.1	80.67	.....	.....	.....	Apr. 26
36	25	8.499	1.7	47.05	79.985	*b* 62.852—	1.273	Apr. 26
36	25	8.413	3.1	0	.....	.....	.....	Apr. 26
35	27.5	8.413	0.1	76.78	.....	.....	.....	Apr. 24
35	27.5	8.424	1.7	46.64	79.288	*c* 63.726—	1.244	Apr. 25
35	27.5	8.445	3.4	0	.....	.....	.....	Apr. 25
37	30	8.459	0.1	73.12	.....	.....	.....	Apr. 27
37	30	8.477	1.9	40.41	76.779	*d* 62.928	1.220	Apr. 27
37	30	8.473	3.6	0	.....	.....	.....	Apr. 27

a Wind, 8.468 miles per hour.
b Wind, 8.500 miles per hour.
c Wind, 8.425 miles per hour.
d Wind, 8.478 miles per hour.

Wheels Nos. 35, 36, 37, and 38 contained 12 plain sails of lineal dimensions, as shown in fig. 19. Each sail made by fastening together 2 sails of No. 18. Wheels otherwise the same as No. 18, and differed from each other only in angles of weather.

Total area of sail surface, 12.937 square feet.

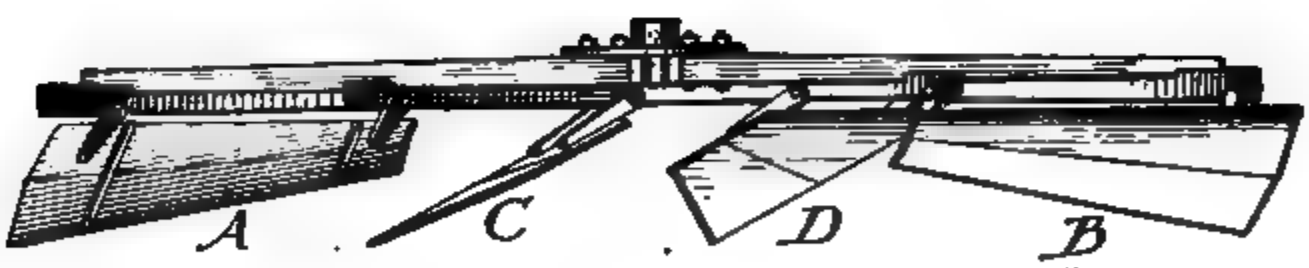


FIG. 18.—Elevation and section of wheel No. 35. (Sail area, 12.937 square feet; efficiency, 0.192.)

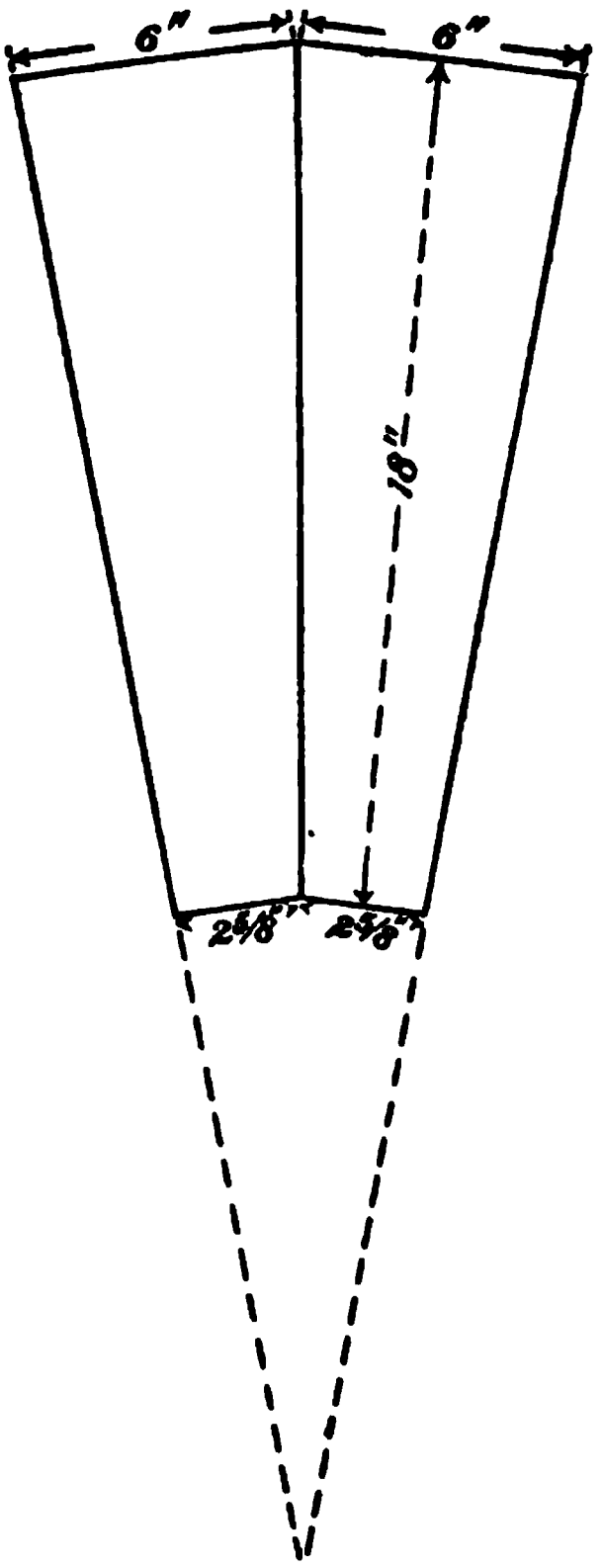


FIG. 19.—Dimensions of sails of wheels.
Nos. 35, 36, 37, and 38.

WHEELS NOS. 40 TO 43.—*Results of experiments.*

No. of wheel.	Angle of weather.	Velocity of wind per hour.	Load applied +0.1 for friction.	Turns of wheel per minute.	Product at maximum.	Product of No. 2 at maximum.	Ratio of products.	Date.
	°	*Miles.*	*Pounds.*					1883.
41	25	8.461	0.1	84.70	.....	.....	.....	May 5
41	25	8.496	1.9	46.81	88.939	65.474=	1.358	May 5
41	25	8.496	3.45	0	.....	.....	.....	May 5
40	27.5	8.498	0.1	82.13	.....	.....	.....	May 3
40	27.5	8.459	1.9	45.74	86.906	62.928=	1.381	May 3
40	27.5	8.519	3.75	0	.....	.....	.....	May 3
42	30	8.491	0.1	77.95	.....	.....	.....	May 7
42	30	8.464	1.9	43.15	81.985	61.180=	1.339	May 7
42	30	8.475	3.9	0	.....	.....	.....	May 7
43	25, 30	8.528	0.1	84.92	.....	.....	.....	May 8
43	25, 30	8.476	1.9	45.92	87.248	62.396=	1.398	May 8
43	25, 30	8.495	3.6	0	.....	.....	.....	May 8

Wind for No. 2 the same as for wheel compared in each case. Wheels contained 12 angular concave sails of lineal dimensions as shown in fig. 21. Each sail made by fastening together two sails of No. 18 at an angle of 165 degrees so as to present concave surface to the wind. Wheels differed only in angles of weather. The sails of No. 43 were twisted, making the angles of weather 25 degrees at outer ends of sails and 30 degrees at inner ends. Total area of sail surface, 12.937 square feet.

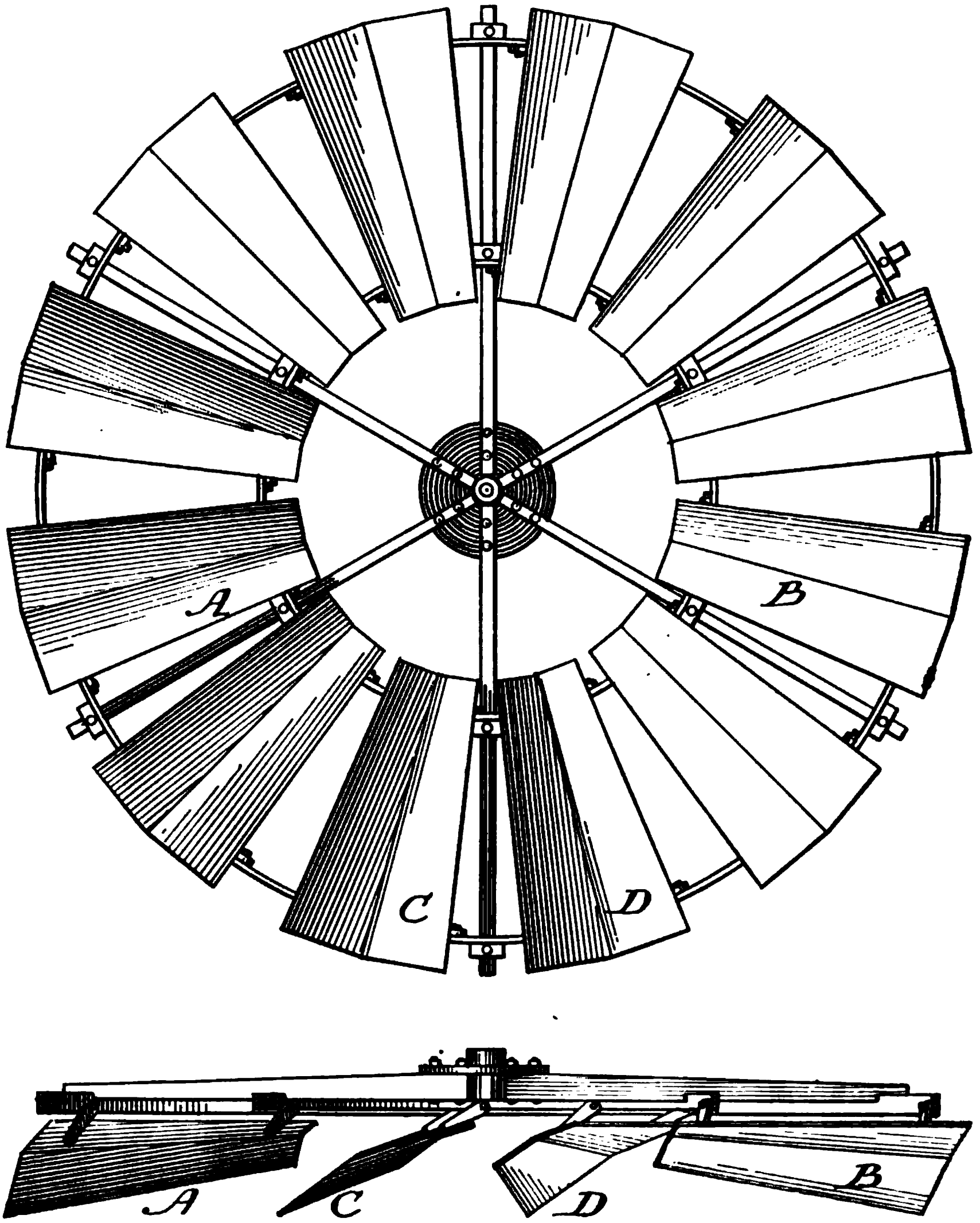


FIG. 20.—Elevation and section of wheel No. 40. (Sail area, 12.937 square feet; efficiency, 0.213.)

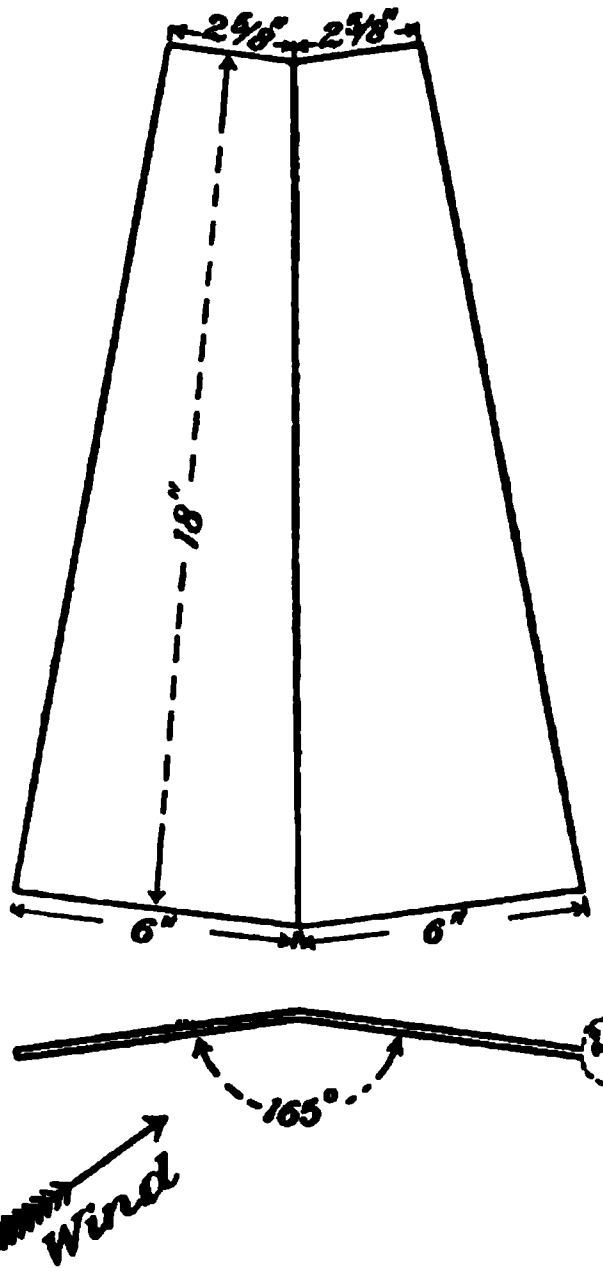


FIG. 21.—Dimensions of concave sails of wheels Nos. 40, 41, 42, and 43.

WHEELS NOS. 40 TO 42.—*Results of experiments.*

No. of wheel.	Angle of weather.	Velocity of wind per hour.	Load applied +0.1 for friction.	Turns of wheel per minute.	Product at maximum.	Product of No. 2 at maximum.	Ratio of products.	Date.
	°	*Miles.*	*Pounds.*					1883.
41	25	6.444	0.1	65.33	.....	.....	.....	May 24
41	25	10.963	0.1	111.10	.....	.....	.....	May 29
41	25	6.459	1.1	35.07	38.577	28.270=	1.365	May 24
41	25	11.022	3.3	55.45	182.985	*a*137.346+	1.332	May 29
41	25	6.404	2.0	0	.....	.....	.....	May 24
41	25	11.111	5.6	0	.....	.....	.....	May 29
40	27.5	6.372	0.1	60.27	.....	.....	.....	May 14
40	27.5	10.890	0.1	106.73	.....	.....	.....	May 21
40	27.5	6.371	1.1	32.90	36.190	26.290=	1.377	May 14
40	27.5	11.041	3.3	56.32	185.856	135.498=	1.372	May 17
40	27.5	6.403	2.1	0	.....	.....	.....	May 14
40	27.5	10.944	6.3	0	.....	.....	.....	May 21
42	30	6.454	0.1	59.13	.....	.....	.....	May 23
42	30	10.974	0.1	103.50	.....	.....	.....	May 23
42	30	6.429	1.2	29.65	35.580	26.037=	1.367	May 23
42	30	10.997	3.7	50.62	187.294	138.897=	1.348	May 22
42	30	6.411	2.3	0	.....	.....	.....	May 23
42	30	11.063	6.9	0	.....	.....	.....	May 22

a Wind, 11.021 miles per hour.

Fig. 22.—Elevation and section of wheel No. 20. (Sail area, 13.072 square feet; efficiency, 0.104.)

WHEELS NOS. 35, 39, 40, AND 44.—*Results of experiments.*

No. of wheel.	Angle of weather.	Velocity of wind per hour.	Load applied +0.1 for friction.	Turns of wheel per minute.	Product at maximum.	Product of No. 2 at maximum.	Ratio of products.	Date.
	°	*Miles.*	*Pounds.*					1883.
35	27.5	8.413	0.1	76.78	.....	.....	.....	Apr. 24
35	27.5	8.424	1.7	46.64	79.288	*a*63.726—	1.244	Apr. 25
35	27.5	8.445	3.4	0	.....	.....	.....	Apr. 25
39	27.5	8.472	0.1	64.52	.....	.....	.....	May 1
39	27.5	8.512	1.9	35.57	67.583	63.650=	1.062	May 1
39	27.5	8.431	3.7	0	.....	.....	.....	May 1
40	27.5	8.498	0.1	82.13	.....	.....	.....	May 3
40	27.5	8.459	1.9	45.74	86.906	62.928=	1.381	May 3
40	27.5	8.519	3.75	0	.....	.....	.....	May 3
44	25, 30	8.482	0.1	84.88	.....	.....	.....	May 9
44	25, 30	8.477	1.9	44.35	84.265	60.952=	1.382	May 9
44	25, 30	8.475	3.6	0	.....	.....	.....	May 9

a Wind, 8.425 miles per hour.

Wheel No. 39 contained 12 sails of lineal dimensions as shown in fig. 23, made by adding to the sails of No. 35, along their rear edges, strips as illustrated, so as to present concave surface to the wind. But the line *a b* was considered the face of the sail as regards angle of weather. For No. 40 see previous description. Sails angular concave.

Wheel No. 44 was the same as No. 3 except that the angles of weather were 25 degrees at outer ends of sails and 30 degrees at inner ends. Sails circular concave.

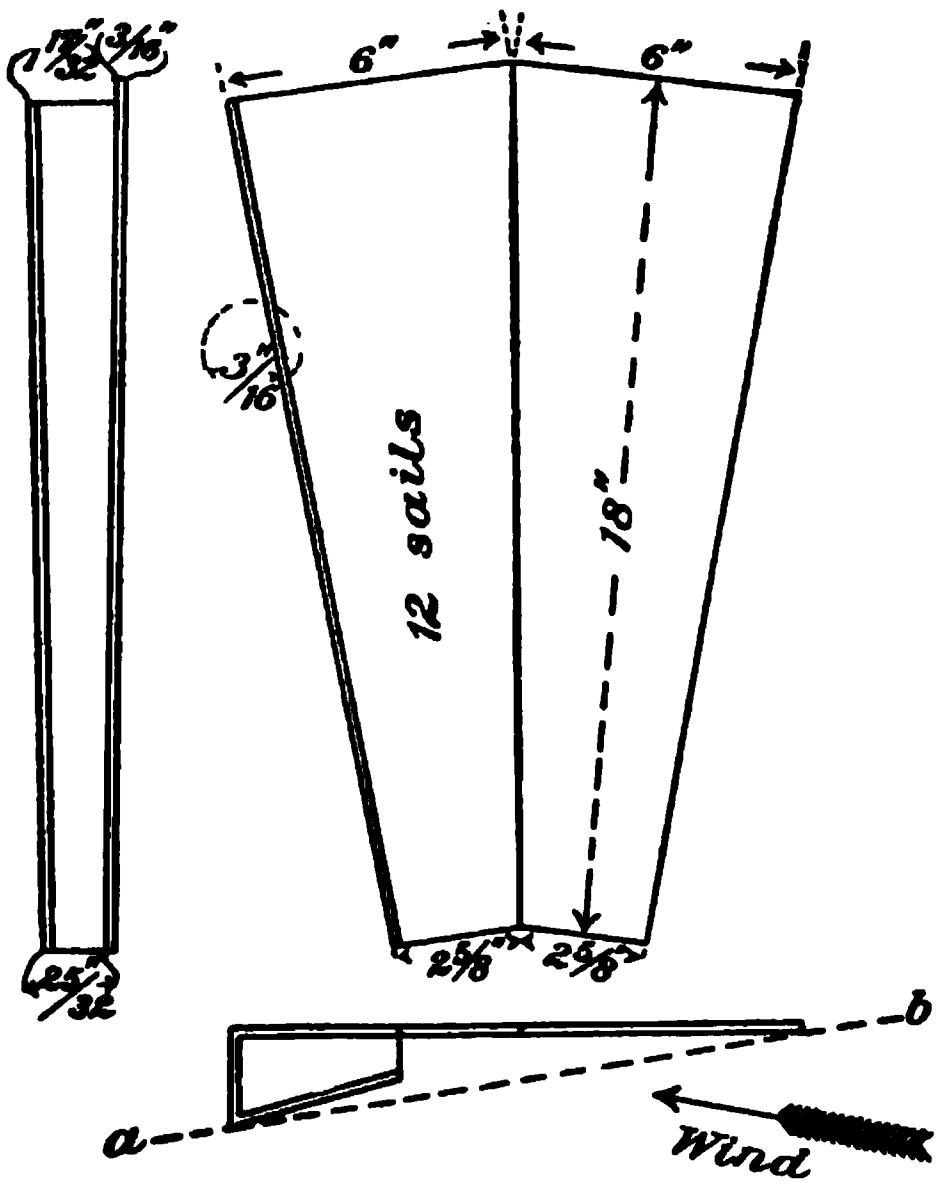
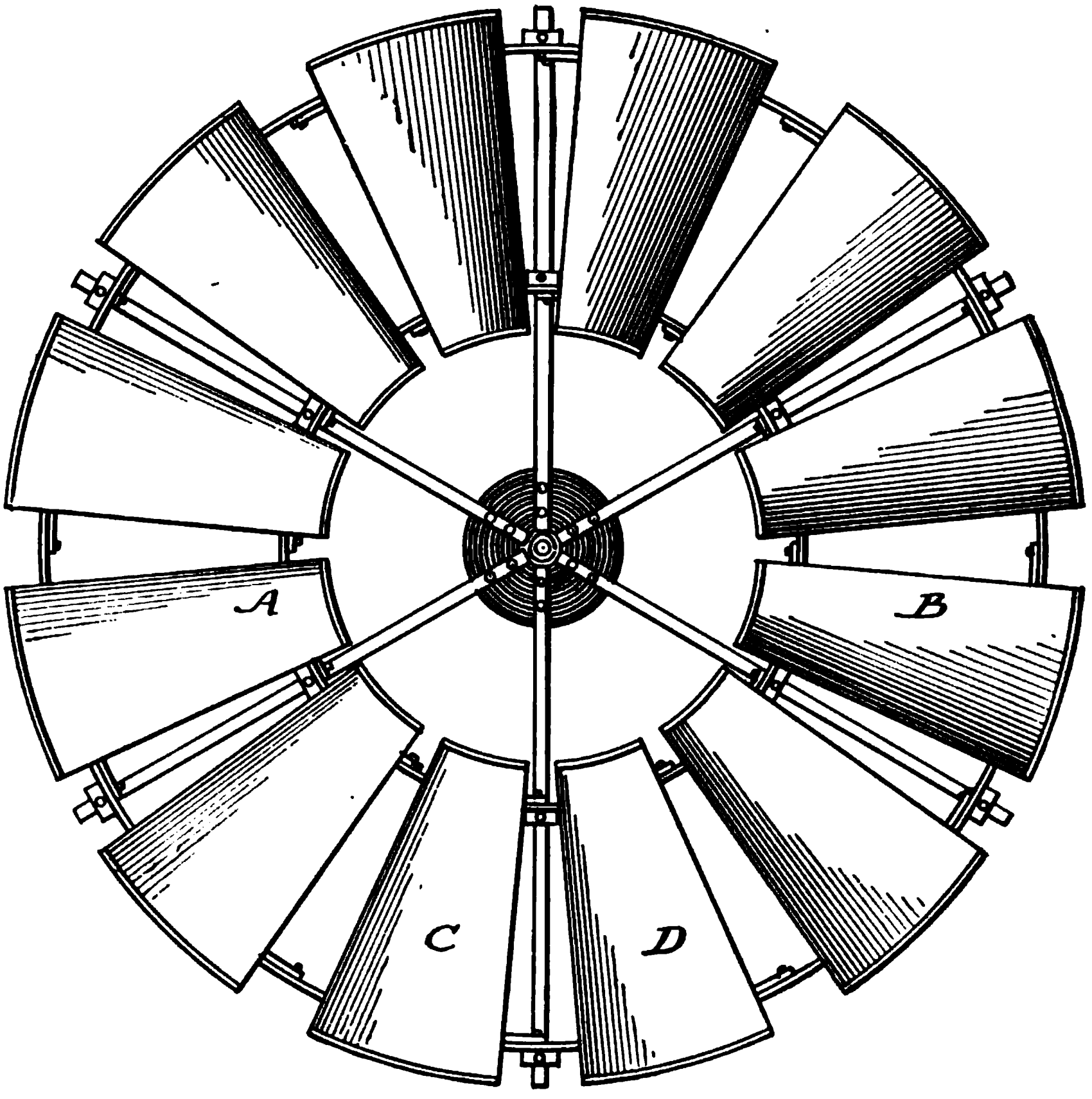


FIG. 23.—Dimensions of sails of wheel No. 39.



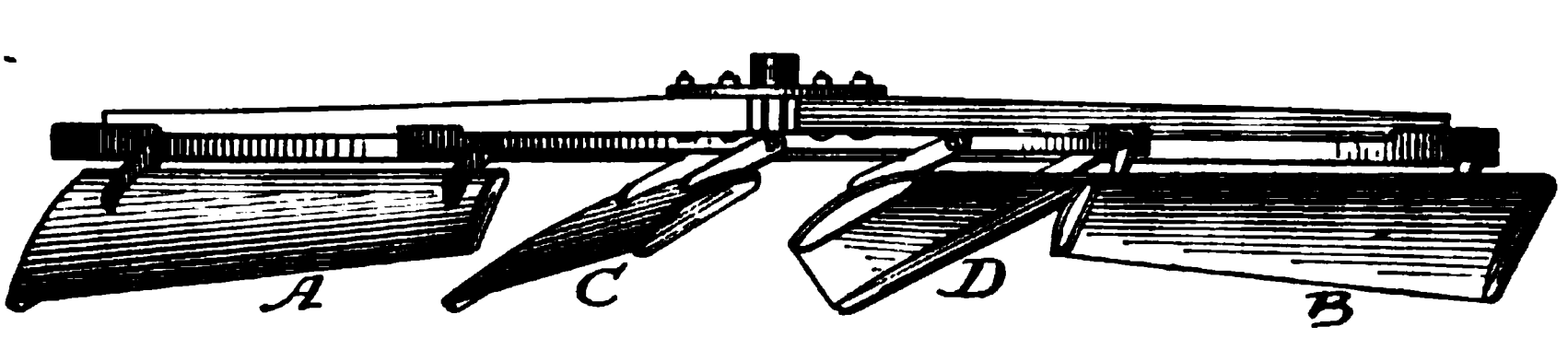


FIG. 24.—Elevation and section of wheel No. 44. (Sail area, 13.500 square feet; efficiency, 0.213.)

WHEELS NOS. 45 TO 49.—*Results of experiments.*

No. of wheel.	Angle of weather. *a*	Velocity of wind per hour.	Load applied +0.1 for friction.	Turns of wheel per minute.	Product at maximum.	Product of No. 2 at maximum.	Ratio of products.	Date.
	°	*Miles.*	*Pounds.*					1883.
46	17.5 at *ab*	11.025	0.1	160.90	.....	.....	.....	June 25
46	20 at *cd*	10.979	2.7	85.19	230.013	*b*135.201—	1.701	June 25
46	25 at *ef*	10.905	4.8	0	.....	.....	.....	June 25
	27.5 at *gh*							
45	20 at *ab*	10.918	0.1	156.63	.....	.....	.....	June 21
45	22.5 at *cd*	11.001	2.9	79.99	231.971	*c*129.195+	1.796	June 20
45	27.5 at *ef*	11.021	5.2	0	.....	.....	.....	June 21
	30 at *gh*							
47	22.5 at *ab*	11.026	0.1	148.68	.....	.....	.....	June 27
47	25 at *cd*	10.980	3.3	73.31	241.923	132.264=	1.829	June 26
47	30 at *ef*	10.944	6.0	0	.....	.....	.....	June 27
	32.5 at *gh*							
48	25 at *ab*	11.125	0.1	141.97	.....	.....	.....	June 27
48	27.5 at *cd*	10.935	3.7	66.79	247.123	132.033=	1.872	June 28
48	32.5 at *ef*	11.014	6.5	0	.....	.....	.....	June 28
	35 at *gh*							
49	27.5 at *ab*	11.187	0.1	136.30	.....	.....	.....	June 29
49	30 at *cd*	10.994	3.9	58.82	229.398	127.116=	1.805	June 29
49	35 at *ef*	10.993	6.6	0	.....	.....	.....	July 2
	37.5 at *gh*							

a Letters in this column refer to fig. 26, p. 61.

b Wind, 10.980 miles per hour.

c Wind, 11.000 miles per hour.

$1.09 = \frac{u}{v} = x =$ ratio of velocity of wind to velocity of outer extremities of sails of No. 48 for maximum work. See page 71.

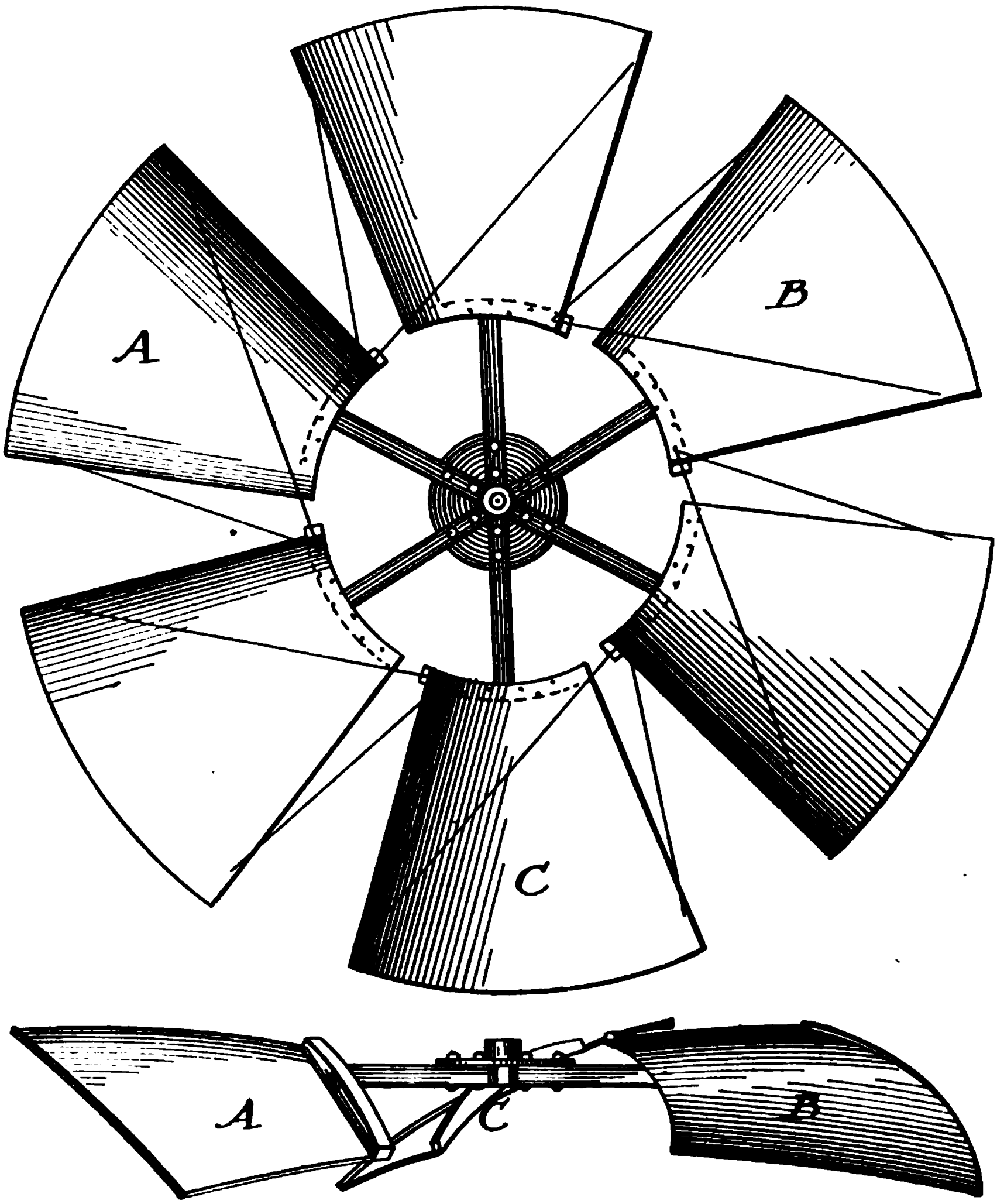


FIG. 25.—Elevation and section of wheel No. 48. (Sail area, 14.159 square feet; efficiency, 0.283.)

Wheels Nos. 45 to 49 differed from each other only in angles of weather, and contained six sails of lineal dimensions as shown in fig. 26. Sails were made by gluing together several layers of paper which formed pasteboard about one-sixteenth of an inch thick. The backs of front and rear edges of each sail were bordered by thin pine strips. Backs of outer edges of sails were likewise bordered and held in shape by stiff curved pine pieces. The inner end of each sail was fastened securely to a thick curved pine piece, which was bolted against the outer end of a short ash arm, so that the sail could be turned on the bolt and set at any desired angle of weather. Thus the arms did not extend beyond the inner ends of the sails. The outer corners of each sail were held in position by two fine brass wires extending to the front inner corner of the succeeding sail. The front and rear edges also curved somewhat, so that the sails presented double concave surfaces to the wind. In constructing these wheels we aimed at avoiding all unnecessary obstruction to the passage of wind between the sails.

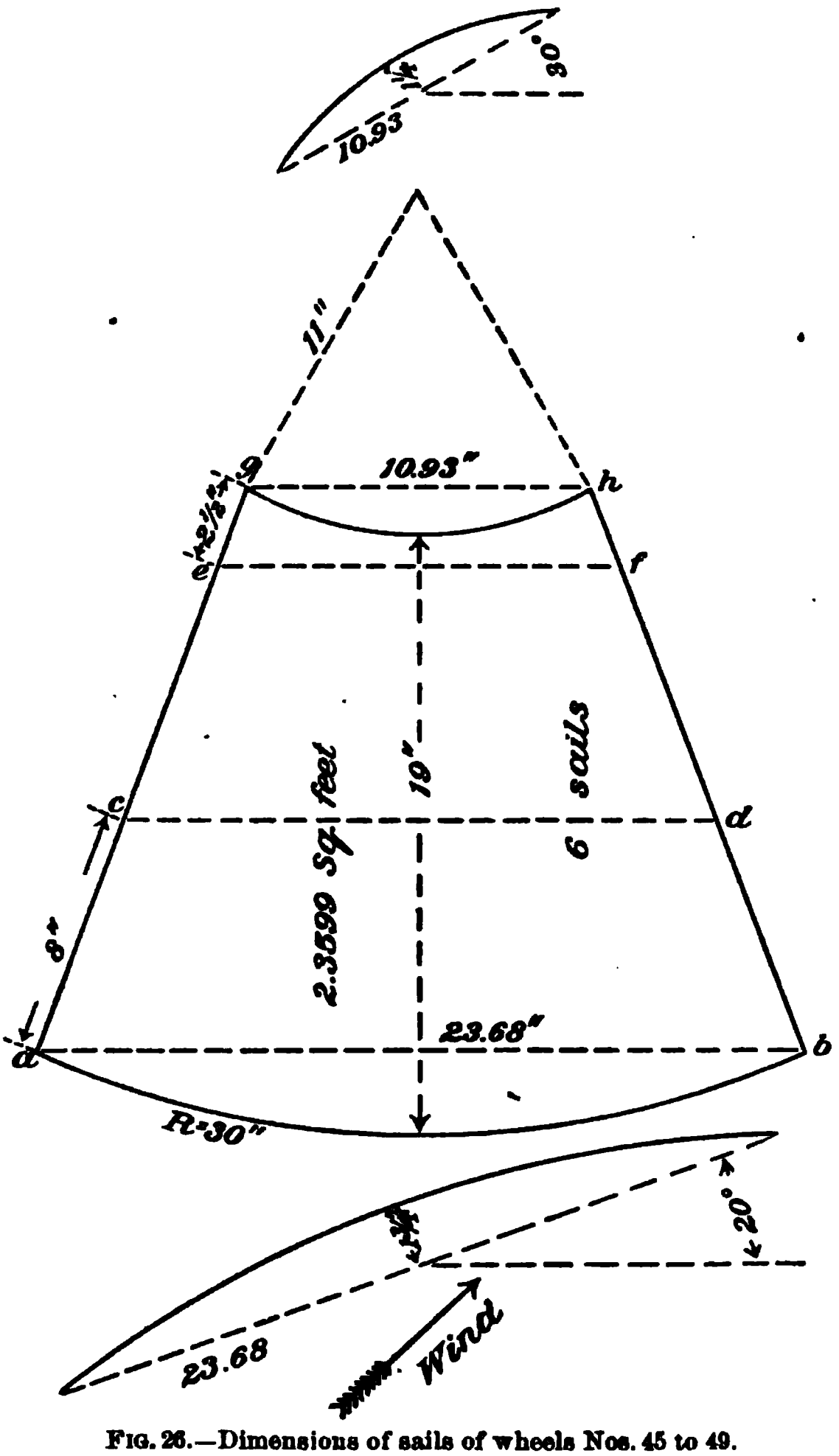


FIG. 26.—Dimensions of sails of wheels Nos. 45 to 49.

WHEELS NOS. 2, 60, AND 61.—*Results of experiments.*

No. of wheel.	Velocity of wind per hour.	Load applied +0.1 for friction.	Turns of wheel per minute.	Product at maximum.	Product of No. 2 at maximum.	Ratio of products.	Date.
	Miles.	*Pounds.*					1883.
60	8.451	1.9	56.50	107.350	58.273—	1.842	Sept. 15
61	8.452	1.9	38.13	*a* 72.447	58.273=	1.243	Sept. 15
2	8.452	1.9	30.67	58.273	58.273=	1.000	Sept. 15

a This product may not have been a maximum, as only the one load, 1.9 pounds, was tried with No. 61.

Wheel No. 60 was the same as No. 48, except that the sails were considerably warped out of original shape from long standing and drying.

Wheel No. 61 was the same as No. 60, except that along the back of each sail a

rectangular piece of pine 1 by 1¼ by 17 inches was fastened to make an obstruction representing an extension of the arm, as illustrated in figs. 28 and 29.

The relative efficiency of No. 60 as compared with No. 61 is indicated by the equation

$$\frac{107.350}{72.447} = 1.482$$

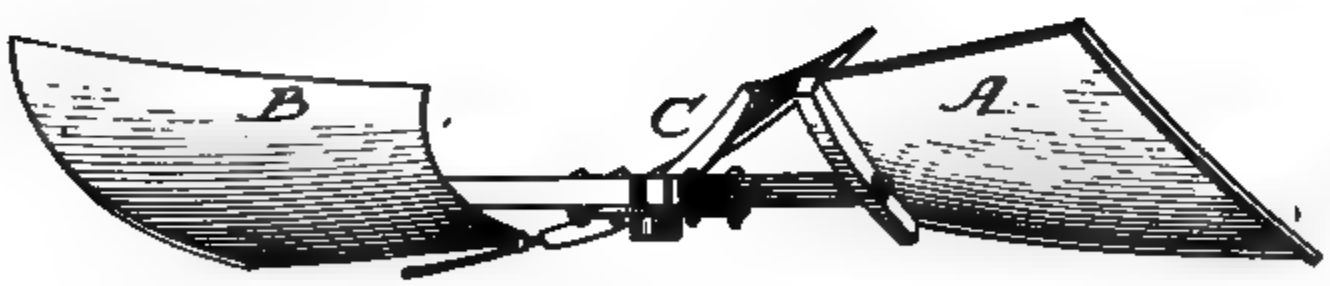


FIG. 27.—Elevation and section of wheel No. 60. (Sail area, 14.150 square feet; efficiency, 0.284.)

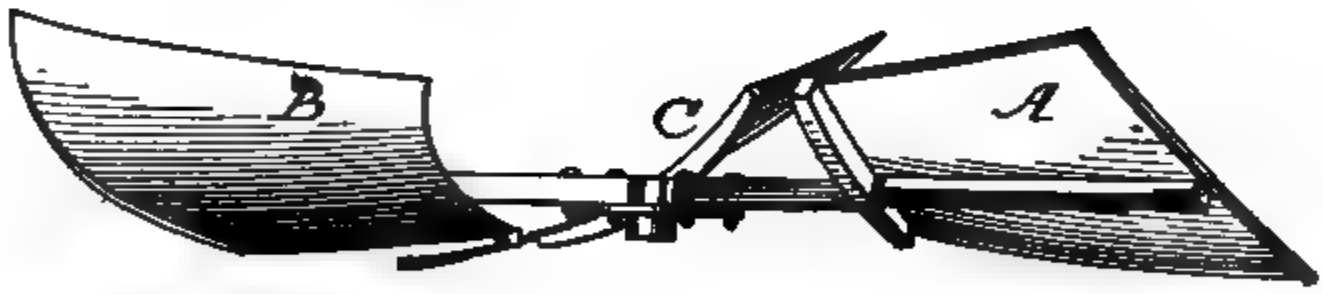
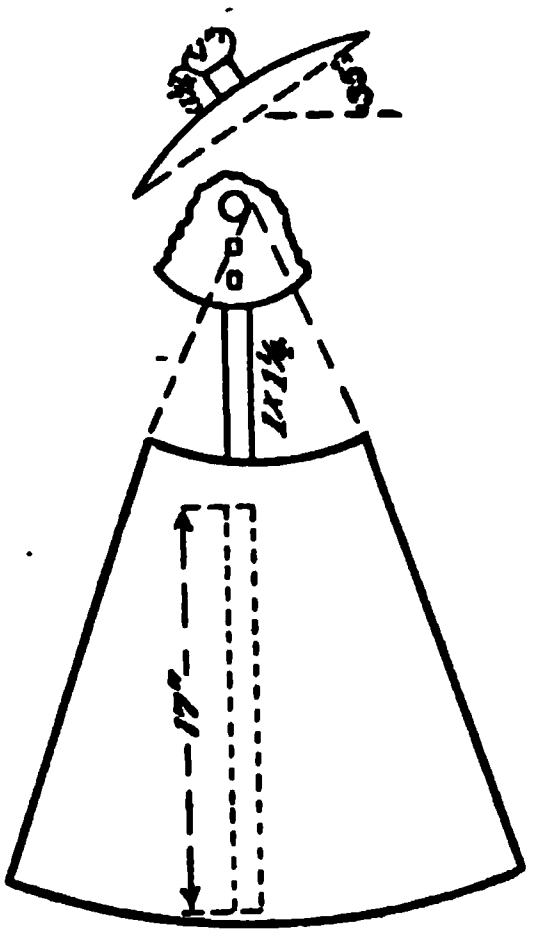


FIG. 28.—Elevation and section of wheel No. 61. (Sail area, 14.159 square feet; efficiency, 0.191.)



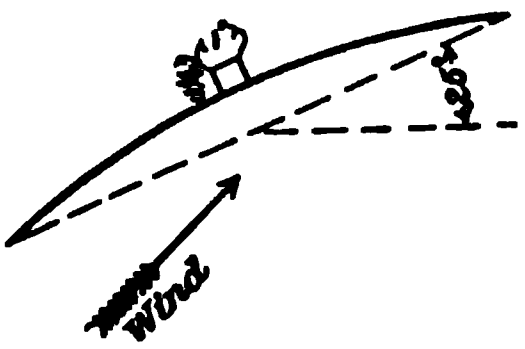


FIG. 29.—Dimensions of sails of wheel No. 61 with obstruction on back.

WHEELS NOS. 2, 49, AND 53 TO 57.—*Results of experiments.*

No of wheel.	Angle of deflector.	Velocity of wind per hour.	Loads applied +0.1 for friction.	Turns of wheel per minute.	Date.
	°	*Miles.*	*Pounds.*		1883.
54	30	10.989	0.1	79.40	July 3
53	45	11.156	0.1	81.80	July 3
55	60	10.985	0.1	80.52	July 3
2	.....	11.007	0.1	77.57	July 3
2	.....	10.975	3.3	37.83	July 5
56	50	10.968	3.3	40.63	July 5
57	50	11.054	3.5	62.63	July 5
49	.....	11.032	3.5	64.22	July 5

Wheels Nos. 53, 54, 55, and 56 were the No. 2 wheel, with stationary rectangular board, $\frac{1}{4}$ by 9$\frac{3}{16}$ by 22 inches, placed in front of sails and with its face set at various angles with plane of wheel, as indicated in table, to act as deflector. Board supported by arm outside of wheel on side farthest from axis of sweep; its lower edge at height of axis of wheel, horizontal, and parallel to plane of wheel. Inner end of board 9 inches from axis of wheel prolonged.

Wheel No. 57 was wheel No. 49, with the same board, described above, similarly used as deflector, except that its lower edge was placed so as to clear the forward edges of sails by about 2 inches at each end.

In the case of Nos. 53 to 56 the center of board deflector was about 7 inches from center of sails.

WHEELS NOS. 2, 49, 51, 52, 58, AND 59.—*Results of experiments.*

No. of wheel.	Position of obstruction.	Velocity of wind per hour.	Load applied +0.1 for friction.	Turns of wheel per minute.	Date.
		Miles.	*Pounds.*		1883.
2	.....	11.141	0.1	78.58	July 3
51	Before ..	11.130	0.1	75.73	July 3
52	Behind..	11.045	0.1	76.16	July 3
49	.....	10.966	3.5	64.53	July 5
58	Before ..	10.972	3.5	55.54	July 5
59	Behind..	10.972	3.5	60.06	July 5

Wheel No. 51 was No. 2, with rectangular board ¼ by 9⅛ by 22 inches placed horizontally in front of the side of wheel farthest from axis of sweep, its face parallel to plane of wheel so as to act as obstruction to wind. Board held at its outer end by means of an arm outside of wheel.

Distance from board to centers of sails, 8 inches.

Distance from inner end of board to axis of wheel prolonged, 9 inches.

Wheel No. 52 was the same as No. 51, except that the board was placed 8 inches behind centers of sails.

Wheel No. 58 was No. 49, with obstrution board above described similarly placed, 8½ inches in front of centers of sails.

Wheel No. 59 was the same as No. 58, except that the board was placed 8½ inches behind centers of sails.

SAILS AT BEST ANGLES OF WEATHER.

Efficiency of various wind wheels at best angles of weather.

No. of wheel.	Area of sail surface.	Angles of weather.	Wind per hour.	Turns of wheel unloaded.	Starting forces.	Load at maximum.	Turns of wheel at maximum.	Product at maximum.	Product of No. 2 at maximum.	Ratio of products.	Value per square foot of sail surface.	Number and indicated character of sails.
	Sq. ft.	°	*Miles.*		*Lbs.*	*Lbs.*						
1	9.190	35	8.452	60.0	.....	1.6	31.69	50.704	.....	.....	.....	30 a
2	18.380	35	8.403	59.0	4.1	1.9	32.875	62.463	62.463	1.000	0.0544	60 a
10	10.688	27.5	8.338	72.0	.....	1.7	39.33	66.861	.....	.....	.....	24 b
19	12.937	27.5	8.500	75.5	3.2	1.9	39.57	75.183	62.719	1.204	.0931	24 c
34	12.937	25, 35	8.502	76.5	3.4	1.7	43.77	74.409	61.655	1.207	.0938	24 c
24	15.000	27.5	8.426	72.7	3.4	1.9	38.87	73.853	60.762	1.212	.0808	24 e
29	17.016	27.5	8.406	73.0	3.6	1.9	39.10	74.290	61.845	1.201	.0706	24 e
35	12.937	27.5	8.424	77.0	3.3	1.7	46.64	79.288	63.726	1.244	.0962	12 cc
36	12.937	25	8.499	80.0	3.0	1.7	47.05	79.988	62.852	1.273	.0984	12 cc
44	13.590	25, 30	8.477	85.0	3.5	1.9	44.35	84.265	60.953	1.382	.1017	12 f
40	12.937	27.5	8.459	81.5	3.6	1.9	45.74	86.906	62.928	1.381	.1067	12 cc
43	12.937	25, 30	8.476	84.5	3.5	1.9	45.92	87.248	62.396	1.398	.1081	12 cc
48	14.159	25, 27.5 32.5, 35	10.935	141.0	6.1	3.7	66.79	247.123	132.033	1.872	.1322	6 g

The velocities of wind given in this table are strictly correct only for products at maximum, though they are very nearly correct also for products of No. 2 at maximum. The velocities of wind are only approximately correct for turns of wheels unloaded and for starting forces. Nothing was added to starting forces for friction, and the 0.1 pound was added to starting forces in preceding tables only for convenience.[1] For further particulars consult preceding tables.

RELATIONS OF THREE DIFFERENT VELOCITIES OF WIND.

Relation of different velocities of wind to maximum products.

Angle of weather.	No. of wheel.	Wind per hour.		Product at maximum.		$\frac{b}{a}$	$\left(\frac{b}{a}\right)^3$	$\frac{B}{A}$	$\frac{B}{A}-\left(\frac{b}{a}\right)^3$	$A\times\left(\frac{b}{a}\right)^3$
		a	*b*	*A*	*B*					
°		*Miles.*	*Miles.*							
	2	6.371	8.459	26.290	62.928	1.328—	2.342	2.394	+0.052	61.571
35	2	8.459	11.041	62.928	135.498	1.305+	2.223	2.153	— .070	139.889
	2	6.371	11.041	26.290	135.498	1.733	5.199	5.154	— .045	136.682
	40	6.371	8.459	36.190	86.906	1.328—	2.342	2.401	+ .059	84.757
27.5	40	8.459	11.041	86.906	185.856	1.305+	2.223	2.139	— .084	193.192
	40	6.371	11.041	36.190	185.856	1.733	5.199	5.135	— .064	188.152
	41	6.459	8.496	38.577	88.939	1.315+	2.274+	2.306	+ .032	87.724
25	41	8.496	11.022	88.939	182.985	1.297+	2.182	2.057+	— .125	194.065
	41	6.459	11.022	38.577	182.985	1.706+	4.965+	4.743	— .222	191.535
	42	6.429	8.464	35.580	81.985	1.317+	2.284+	2.304+	+ .020	81.265
30	42	8.464	10.997	81.985	187.294	1.299+	2.192	2.284+	+ .092	179.711
	42	6.429	10.997	35.580	187.294	1.707+	4.974	5.264	+ .290	176.975

Conclusion.—Maximum products vary as the cubes of the velocities of wind. Some allowance must be made for the differences in time and condition of air under which the various products were obtained; considering these differences, there is no unaccountable variation from the law of cubes.

Relation of different velocities of wind to starting forces.

Angle of weather.	No. of wheel.	Wind per hour.		Starting forces.		$\frac{b}{a}$	$\left(\frac{b}{a}\right)^2$	$\frac{B}{A}$
		a	*b*	*A*	*B*			
°		*Miles.*	*Miles.*	*Pounds.*	*Pounds.*			
	2	6.380	8.405	2.3	4.1	1.319—	1.740	1.783
35	2	8.405	10.989	4.1	7.0	1.307	1.708	1.704
	2	6.380	10.989	2.3	7.0	1.722	2.965	3.043
	40	6.403	8.519	2.0	3.65	1.330	1.769—	1.825
27.5	40	8.519	10.944	3.65	6.2	1.285	1.651	1.699
	40	6.403	10.944	2.0	6.2	1.709	2.921—	3.100
	41	6.404	8.496	1.9	3.35	1.327—	1.761	1.763
25	41	8.496	11.111	3.35	5.5	1.308—	1.711—	1.642
	41	6.404	11.111	1.9	5.5	1.735	3.010	2.895
	42	6.411	8.475	2.2	3.8	1.322	1.748	1.727
30	42	8.475	11.063	3.8	6.8	1.305—	1.703	1.789
	42	6.411	11.063	2.2	6.8	1.725	2.976—	3.091

Conclusion.—Starting forces vary as the squares of the velocities of wind.

[1] See starting forces, "S," p. 25.

Relation of different velocities of wind to speed of unloaded wheels.

Angle of weather.	Nos. of wheels.	Wind per hour.		Turns unloaded.		$\frac{b}{a}$	$\frac{B}{A}$
		a	*b*	*A*	*B*		
°		*Miles.*	*Miles.*				
35	2	6.437	8.511	43.78	59.62	1.322	1.362
	2	8.511	10.996	59.62	78.68	1.292	1.320
	2	6.437	10.996	43.78	78.68	1.708	1.797
27½	40	6.372	8.498	60.27	82.13	1.334	1.363
	40	8.498	10.890	82.13	106.73	1.281	1.300
	40	6.372	10.890	60.27	106.73	1.709	1.771
25	41	6.444	8.461	[1]65.33	84.70	1.313	1.296
	41	8.461	10.963	84.70	111.10	1.296	1.312
	41	6.444	10.963	[1]65.33	111.10	1.701	1.701
30	42	6.454	8.491	59.13	77.95	1.316	1.318
	42	8.491	10.974	77.95	103.50	1.292	1.328
	42	6.454	10.974	59.13	103.50	1.700	1.750

[1] Too great because of outside wind and perhaps other causes.

Conclusion.—Speeds of unloaded wheels increase in somewhat greater ratio than the velocities of wind.

All wind wheels tested were 5 feet in external diameter, and all sails were 18 inches long except in the case of Nos. 46 to 49 and Nos. 60 and 61, in which wheels the sails were 19 inches long, 1 inch being added for support at inner ends.

AUTOMATIC BRAKE ADJUSTER.

On March 13, 1883, the dynamometer was improved by the addition of an automatic brake adjuster. Previous to this date the brake was adjusted as described on page 23 through regulating the tension of the adjusting cord by sliding a weight in and out on a lever attached to the cord.

This method required time and patience in order to get an exact balance between the load applied and the friction of brake, and it was also necessary to exercise judgment in determining when the balance was exactly even. Furthermore, an exact balance was not always retained during a test of one minute, as required for accuracy, and frequent readjustments were constantly necessary. The labor involved in adjusting and maintaining a proper balance of friction and load became very tiresome when kept up for from six to eight hours continuously, as was frequently the case; and weariness was detrimental to the perceptions as well as to the judgment. Therefore, an automatic adjuster became very desirable, both for relief to the mind and for the increase of accuracy.

The automatic brake adjuster, after various attempts and failures, was finally constructed as follows: The brake and adjusting cord were

left substantially as previously described on page 23; but one end of a short rod three-sixteenths inch in diameter was attached to the cord where it was brought back from the brake in a direction parallel to the axis of the shaft. The other end of this rod had a full thread, 32 to the inch, and a nut which was fastened to a wooden wheel *A*, 6½ inches in diameter. This wheel was supported on a hollow tube through which the rod passed, and against the outer end of which the nut rested. The nut communicated tension to the adjusting cord, which was tightened by revolving the wheel *A* in one direction and loosened by turning the wheel in the opposite direction. This wheel *A* was driven by a small wheel *B*, 1½ inches in diameter, fastened to a large wheel *C*, 5 inches in diameter. This wheel *C* was driven by another small wheel *D*, $1\frac{5}{16}$ inches in diameter, fastened to a large wheel *E*, 4 inches in diameter, the periphery of which was constantly in contact with another wheel *F* of the same dimensions. The wheels *E* and *F* were supported by a tilting frame which oscillated on a supporting rod passing through the centers of the wheels *B* and *C*, but not touching them. The wheels *E* and *F* hung in close proximity to the rear end of wind wheel shaft, $1\frac{3}{16}$ inches in diameter, so that a slight movement of the tilting frame would bring either of the wheels *E* or *F* in contact with the shaft; and if wheel *E* came in contact with the shaft while revolving, the adjusting cord would be drawn tighter, and if wheel *F* came in contact with the shaft, the tension of the cord would be relaxed. The tilting frame was connected with the brake and partook of its oscillating motion, so that if the friction of the brake was too small to lift the load applied, wheel *E* would be in contact with the shaft and would cause an increase in the friction of the brake until the load was lifted and contact between wheel *E* and the shaft broken. If the friction of the brake was too great, the load applied was raised until wheel *F* came in contact with the shaft so as to cause a diminution of friction until contact of wheel *F* with the shaft was broken. It was very easy to tell at any time if friction of brake was too little or too great, by simply watching the direction of movement of wheels *E* and *F*. This did not require the exercise of judgment, as errors of balance were greatly magnified to the eye and made self-correcting. All contacts between the various wheels, *A*, *B*, *C*, *D*, *E*, *F*, and shaft were frictional. Wheels *B*, *C*, were entirely supported by contact of peripheries with wheels *A* and *D*, and wheel *E* was so hung to a separately hinged support that its own weight produced a uniform pressure against wheel *F*. The entire automatic system was supported independently of the brake; the connection with the brake served only to give the necessary oscillatory movement to the tilting frame, which was also balanced both as regards the action of gravity and centrifugal force when the sweep was in motion.

Some power of the wheel was necessarily consumed by the automatic adjuster, but it may be ascertained, from the description and dimensions given, that a point in the wind wheel 1 foot from the center

of shaft would move in tightening the adjusting cord about 67,019 times as far as the threaded rod attached to the cord; from this it follows that the pressure of the brake against the cylinder was $67,019 \times 16 = 1,072,304$ times as great as the force required at 1 foot from the center of shaft to produce the pressure, without considering the friction of the automatic system. And if we make the very liberal allowance of one-third additional force required to overcome the friction of the automatic system and call the friction of brake 0.05 of pressure, remembering that the diameter of cylinder was $5\frac{1}{4}$ inches, we may readily find that the force required to produce friction of brake equal to any load would be only about $\frac{1}{13964}$ part of that load at the same distance from center of shaft. Hence, it will be seen that the power consumed by the automatic brake adjuster was too minute materially to affect products and called for no correction.

THEORY OF THE ACTION OF THE WIND UPON THE SAILS OF WINDMILLS.

Where a fluid moves along in a current, the direct force of the current is expressed in pounds by the formula Mv, in which v represents the velocity of flow in feet per second and M is the mass of fluid which flows per second past a fixed point. $M = \frac{W}{g}$, W representing weight in pounds of fluid passing the fixed point per second, and $g = 32.2$, the constant for gravity. [1]

Where a current acts against a surface and its direction is simply changed by the surface without impeding its velocity, a direct pressure $= Mv$ is exerted by the impinging current in the direction of its motion, and an equal pressure is exerted by the current as it escapes from the surface, $= Mv$, in a direction opposite to the direction of escape.

If the current impinges against a surface which is itself in motion, the relative velocities of the impinging and escaping currents must be considered in determining the forces which act upon the moving surface. Of the two equal forces due to impingement and escape of current the sum of those components acting in the direction of motion of the surface constitutes the useful effort designated by P, and if the velocity per second of motion of surface is called u, the useful work yielded per second by the current will be represented by Pu. The actual energy of the current is represented [2] by $\frac{Mv^2}{2} = \frac{Wv^2}{2g}$. The ratio of useful work to actual energy is termed efficiency, and is represented [3] by the symbol $1 - k = \frac{2Pug}{Wv^2}$.

In deducing formulæ to represent the action of wind upon the sails of windmills we have proceeded upon the assumption that the sail

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[1] See Rankine's Steam Engine, articles 14 and 144, Case III.
[2] See Rankine's Steam Engine, article 31.
[3] See Rankine's Steam Engine, article 92.

should be of such form as most effectually to change the air current into a direction as nearly as possible opposite to the direction of the sail's motion. We have also assumed, in accordance with principles stated by Rankine concerning the action of water on vanes, that the receiving edge of the sail should be tangent to the relative direction of the impinging current. These conditions are represented in fig. 30, in which $DE = v$ = direction and velocity of wind, $AE = u$ = direction and velocity of sail, and α = angle DEA, which the direction of wind makes with direction of motion of sail.

Then, DA = relative direction and velocity of current with reference to sail AB.

Let $BG = AD$ = relative direction and velocity of current as it escapes from the sail.

β = angle BGF which relative direction of escaping current makes with direction of sail's motion.

Then

$$DC = v \sin \alpha.$$
$$AC = u - v \cos \alpha.$$
$$AD = \sqrt{v^2 \sin^2 \alpha + (u - v \cos \alpha)^2}.$$
$$GF = GB \cos \beta = AD \cos \beta.$$
$$GF = \cos \beta \sqrt{v^2 \sin^2 \alpha + u^2 - 2uv \cos \alpha + v^2 \cos^2 \alpha}.$$
$$GF = \cos \beta \sqrt{v^2 + u^2 - 2uv \cos \alpha}.$$

If Q = volume in cubic foot of air acting on sail in 1 second, and d = weight in pounds of 1 cubic foot of air, we have for useful effort

$$P = \frac{dQ}{g}(GF - AC).$$
$$P = \frac{dQ}{g}[\cos \beta \sqrt{u^2 + v^2 - 2uv \cos \alpha} - u + v \cos \alpha].$$

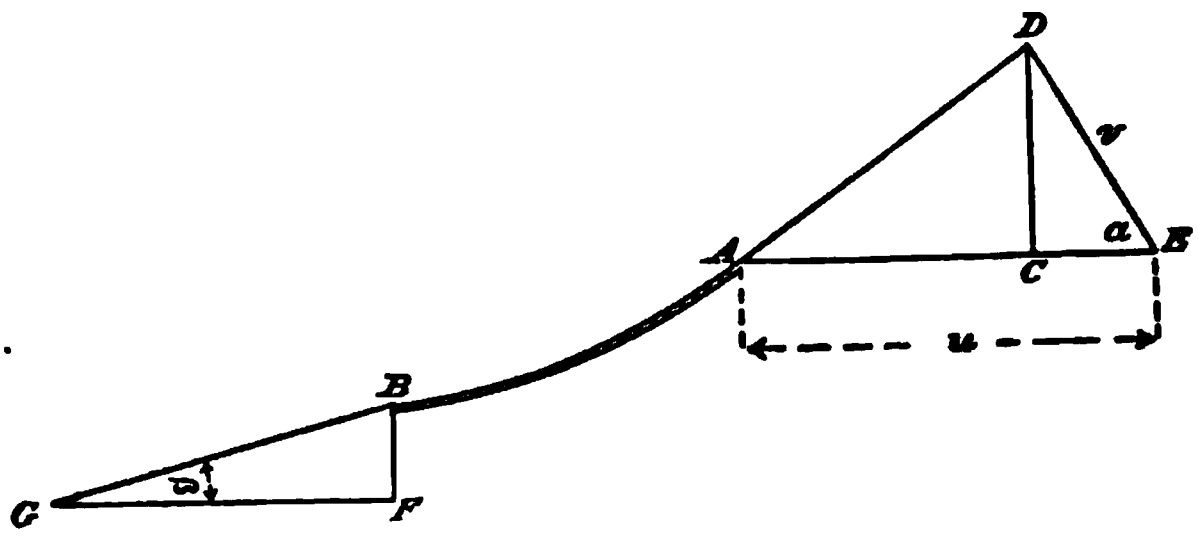

FIG. 30.—Action of wind on a sail.

The expression for useful work becomes

$$Pu = \frac{dQ}{g}[u \cos \beta \sqrt{u^2 + v^2 - 2uv \cos \alpha} - u^2 + uv \cos \alpha]. \qquad (A)$$

Dividing by $\frac{Mv^2}{2} = \frac{dQv^2}{2g}$ we have for efficiency

$$1 - k = 2\frac{u}{v} \cos \beta \sqrt{1 + \frac{u^2}{v^2} - 2\frac{u}{v} \cos \alpha} - 2\frac{u^2}{v^2} + 2\frac{u}{v} \cos \alpha.$$

Or letting $\frac{u}{v}=x$,

$$1-k=2x\cos\beta\sqrt{1+x^2-2x\cos\alpha}-2x^2+2x\cos\alpha. \qquad (B)$$

By substituting $-\cos\gamma$ for $\cos\beta$ in formula (A) the expression for Pu becomes the same as formula (6) on page 165 of Rankine's Steam Engine.

To find an expression for x corresponding to maximum efficiency, for general values of α and β would, as Rankine remarks, be more trouble than it is worth. But in the case of the windmill we know that $\alpha=90°$, which makes $\cos\alpha=0$. Hence, formula (B) becomes

$$1-k=2\cos\beta\sqrt{x^2+x^4}-2x^2. \qquad (C)$$

The relation between x and β corresponding to maximum and minimum efficiency will be expressed by the formula

$$x^2=-\tfrac{1}{2}\pm\tfrac{1}{2}\sqrt{\frac{1}{1-\cos^2\beta}}=-\tfrac{1}{2}\pm\frac{1}{2\sin\beta}. \qquad (D)$$

From this it appears that if $\beta=0$, as it should for maximum efficiency, x becomes infinite. That is, the theoretical efficiency of the windmill becomes greater as the speed of the sails increases indefinitely.

If $\beta=0$ formula (C) shows that

For $x=1$, $1-k=.828$; for $x=2$, $1-k=.944$;
For $x=3$, $1-k=.973$; for $x=10$, $1-k=.9974$;

or almost perfect efficiency when the speed of the sails is 10 times the velocity of the wind. Perfect efficiency, however, could not be reached unless $x=\infty$.

Of course the formula does not take into account the retarding effect of friction, resistance of medium, and other causes which make it impossible to realize in practice anything like the efficiency indicated by the formula; and in practice β can never equal 0 as it should for perfect efficiency.

Letting $x=1$ and assigning more probable values to β, formula (C) gives

For $\beta=10°$, $1-k=.785$.
For $\beta=20°$, $1-k=.657$.
For $\beta=30°$, $1-k=.449$.

Theoretically the analysis of the action of wind on the sails of a windmill corresponds to the analysis of the action of water on a reaction wheel or turbine without guide blades.[1] In the windmill, as commonly made, angle α in our formula (B) is necessarily 90°; but the formula suggests guide blades or deflectors corresponding to those of parallel-

[1] See Rankine's Steam Engine, pp. 197 and 206.

flow turbine water wheels. For if we give to x and β any probable finite values, we may find the values of angle α corresponding to maximum efficiency from the formula,

$$\cos \alpha = \tfrac{1}{2}\left(x + \frac{1}{x} - x \cos^2 \beta\right) \qquad \text{(E)}$$

in which—

For $x = 3$ and $\beta = 10°$, $\alpha = 77° 46'$;
For $x = 2$ and $\beta = 10°$, $\alpha = 73° 44'$;
For $x = 3$ and $\beta = 20°$, $\alpha = 70° 00'$;
For $x = 2$ and $\beta = 20°$, $\alpha = 68° 28'$;
For $x = 1$ and $\beta = 20°$, $\alpha = 56° 03'$.

These assumptions for x and β are plausible, as x varies greatly between the outer and inner extremities of a sail, and β should be assumed as the average angle of escape of the whole cylinder of air intercepted by the wheel, and not as the angle merely of that portion of air which comes immediately in contact with the sails, or which the sails directly intercept.

It is to be noticed that formula (B) does not take into account as such the angle of weather, which seems to be incidental to practice but not to theory.

As we have already pointed out, our formula (A) is substantially the same as Rankine's general formula for the action of water on vanes. But Rankine, instead of applying his general formula to windmills, breaks entirely away from it, and uses another formula specially deduced for the "case of a flat vane oblique to the jet," and which he calls the "easiest method of solution."[1] But that his "easiest method" is erroneous even in the case specified, is evidenced by the fact that a very different result is obtained by the application of his general formula.

We pointed out the nature of Rankine's error in a paper dated December, 1881, which was submitted to Prof. R. H. Thurston, of Stevens Institute of Technology. Other writers on windmills have made the same mistake. The theory and formula which we have here given are abstracted from a paper also prepared for Professor Thurston, dated March 6, 1882.

Theoretical considerations were kept in view during our dynamometric experiments. It will be seen from the preceding tables of experiments how closely the results obtained in practice correspond to theory.

DISCUSSION OF RESULTS.

THERMOMETRIC AND BAROMETRIC INFLUENCES.

The preceding pages are substantially an unchanged reproduction of the records made by the writer for the United States Wind Engine and Pump Company of Batavia, Illinois, during and immediately after the experiments in 1883. The only alteration we have presumed to

[1] See Rankine's Steam Engine, pp. 169 and 215.

make is in omiting the records of barometric readings which were made during the earlier experiments. No barometric readings were taken or recorded after December 21, 1882.

CONSTRUCTION OF TABLES.

In tables on pages 28 to 46 results are recorded for a greater or less number of loads increasing usually by increments of two-tenths pound. Although the results are always given in the order of increasing loads, they were not always obtained in that order, as is indicated by the marginal dates at the right-hand side of some of the tables. Enough tables were prepared in this manner to show how in general the speeds of revolution decreased as the loads increased, and how the products increased with the increasing loads up to a certain point, which marks the maximum, and then decreased continually with further increments of load until the vanishing point was reached. It was not necessary to try many different loads in order to find the best load corresponding to the maximum product. This could be ascertained by a few trials, and as our main object was to get at the relative merits of the wheels tested, we subsequently abandoned the practice of trying so many different loads, and confined our attention more strictly to the determination of maximum products, starting forces, and unloaded speeds; so that the remaining tables on pages 47 to 65 show in general only these three results for each wheel and comparisons of results with different wheels. Special explanations relative to special tables are given elsewhere.

EXTREME RESULTS.

In addition to the original tables already presented, we have collected together in the following table the maximum products given by wind wheel No. 2 at the various dates it was tested in connection with other wheels. It may be observed that the lowest maximum product was 58.083, recorded on April 10, 1883, and that the highest product for wind of nearly the same velocity was 65.474, recorded on May 5, 1883. The products for the same wheel thus vary nearly 13 per cent on different days. Taking the temperature and barometric pressure of Chicago on the two days above mentioned as approximately the same as at Batavia, 35 miles distant due west, we are able to account for but little more than 2 per cent of the variation. Notice also that in wind of about 11 miles per hour, the lowest maximum product was 124.839, recorded on July 5, 1883, and that the highest product was 138.897, recorded on May 22, 1883. Here a variation of over 11 per cent appears for the same wheel on different days. In this case the difference in temperature and barometric pressure at Chicago might account for a little more than 8 per cent of the variation.

Maximum product of wheel No. 2 at different dates.

Velocity of wind per hour.	Product at maximum.	Date.	Velocity of wind per hour.	Product at maximum.	Date.
Miles.		1883.	*Miles.*		1883.
8.485	58.083—	Apr. 10	8.478	62.928—	Apr. 27
8.499	62.719+	Apr. 11	8.496	65.474=	May 5
8.487	62.966—	Apr. 12	8.459	62.928=	May 3
8.463	62.225	Apr. 16	8.464	61.180=	May 7
8.461	58.957—	Apr. 17	8.476	62.396=	May 8
8.432	62.966+	Apr. 9	8.512	63.650=	May 1
8.432	60.762	Apr. 6	8.477	60.952	May 9
8.455	61.902—	Apr. 6	8.452	58.273	Sept. 15
8.398	61.142	Apr. 4	11.041	135.498	May 17
8.395	61.370+	Apr. 3	11.054	126.984	July 2
8.403	62.463—	Mar. 14	11.021	137.346	May 29
8.410	61.845—	Mar. 27	10.997	138.897	May 22
8.427	62.478+	Mar. 28	10.980	135.201	June 25
8.419	61.864—	Mar. 30	11.000	129.195	June 20
8.446	61.408+	Mar. 31	10.980	132.264	June 26
8.501	61.655+	Apr. 18	10.935	132.033	June 28
8.488	63.802	Apr. 28	10.994	127.116	June 29
8.500	62.852—	Apr. 26	10.975	124.839	July 5
8.425	63.726—	Apr. 25			

INFLUENCE OF OUTSIDE WIND.

Experiments were conducted in a closed room to insure the exclusion of all natural wind. The exclusion of wind from the inclosed space, however, was not perfect. The wind circling around the outside of the building undoubtedly at times caused a slight circulation of air inside, which may have been more potent in causing variations in results than either thermometric or barometric influences. The windows were always kept carefully closed during experiments, and the doors also were guarded as much as possible. The doors, however, were necessarily used, and we distinctly remember being obliged to discard many measurements on account of doors being opened during tests on windy days. But unless a door was opened during a test we considered that errors from influence of outside wind were sufficiently guarded against by our practice of comparing all results with those obtained with wheel No. 2, under like conditions, as explained in the original records.

STANDARD OF COMPARISON.

As stated in the original record, wheel No. 2, which we always used as a standard for comparison, was modeled after the Halliday 10-foot wind wheel; that is to say, the slats, arms, etc., were the same in number

and of the same relative dimensions on a scale of one-half. There was, however, this difference, that the Halliday was what is called a section wheel, having pivoted sections for the purpose of regulation. Wheel No. 2 had all its parts rigidly fixed with reference to each other, and therefore was more like the solid wheels in common use at the time. The solid wheels were really copies of the Halliday, so far as the sails or slats and the arms were concerned. The only essential difference between section and solid wind wheels related to the method of stopping and governing their motion. Different makers of both styles of wheels had their own notions about angles of weather and proportions of sail surface. The Halliday 10-foot wheel had its slats set at an angle of 35° with the plane of motion. The slats were as thin as was consistent with safety, considering that their material was wood, and they were trimmed to a sharp edge, so as to cut the air as much as possible.

Nearly all wind wheels in use at the time of our experiments in 1882–83 were made with narrow wooden slats, similar in general appearance to our wheel No. 2. Some makers adopted greater angles of weather than 35 degrees, and even let the sails overlap so as to boast of greater sail area for their wheels as a basis for claiming greater power. A 45-degree angle of weather was not uncommon, and the slats were often made thicker than those of the Halliday wheel; besides, they were not always trimmed to an edge in front.

In adopting as our standard of comparison a wheel modeled after the 10-foot Halliday, we believe that we made use of the best model available to represent wind wheels in general as then constructed.

CORRECTIONS FOR AXLE FRICTION.

In the earlier tables 0.3 pound was added to all applied loads. This 0.3 pound was arrived at as explained after the table on page 38, and was in reality an estimate of frictional resistance to starting, or to slow motion. As authorities stated that friction was the same at all velocities, we adopted 0.3 pound as approximately representing the frictional resistance of the journals without regard to speed. We afterwards learned that the axial friction diminished greatly with increase of speed of revolution, as is made evident by comparing the speeds of the same wheels after starting friction was greatly reduced with the speeds before reduction of friction under the same applied loads and also unloaded. (See original records after table on page 38.)

Wheels Nos. 2, 18, and 19, especially, may be compared. Subtract 0.3 from loads in the tables giving average results for wheels Nos. 2, 18, and 19, on pages 29, 43, and 44, and subtract 0.1 in tables on pages 27 and 47 to obtain applied loads. Evidently there is very little difference between the axial frictions in the two cases for unloaded wheels.

We can not now, after a lapse of more than fifteen years, undertake to assert what the axial friction previous to March 13, 1883, should have been called for different speeds. But if in the table on page 29 we

call friction 0.15 pound, we shall find the maximum product to be 61.846 instead of 66.860, as there recorded. And as this correction would make this table agree substantially with the general results of the table on page 74, it seems probable that 0.15 pound is about the right amount to allow for friction in the first twenty-one tables to obtain maximum products.

If in the table on page 43 for wheel No. 18 we call friction 0.15 pound, the maximum product will become 76.869, obtained January 13, 1883. On April 10, 1883, the same wheel, No. 18, gave as maximum product 69.300, showing a variation of more than 12 per cent. But the United States Signal Service records in Chicago show for these two dates a difference of more than 1 inch in the barometric column, and about 39 degrees difference in temperature, which will account for a variation of about 12 per cent. Again, if in the table on page 44 for wheel No. 19 we call friction 0.15 pound, the maximum product will become 82.130, obtained January 18, 1883. On April 11, 1883, the same wheel, No. 19, gave as maximum product 75.185, showing a variation of over 9 per cent. The differences in temperature and barometric pressure as given for these two dates by the Signal Service records at Chicago would account for a variation in atmospheric density of just about 9 per cent. These three wheels, Nos. 2, 18, and 19, are the only ones tested both before and after the reduction of friction on March 13, 1883. While the products as recorded in the tables in which 0.3 pound was added to loads are all too large, their comparative values are not greatly distorted by the excessive allowance for axial friction.

The smaller allowance for axial friction will sometimes make the maximum product correspond to the next greater applied load, as in the case of wheel No. 19, page 44. But in the tables on pages 29 and 43, after allowing 0.15 pound instead of 0.3 pound for friction, the maximum products still correspond to the same applied loads and the same speeds of revolution as before.

AERIAL FRICTION.

So far we have not attempted to estimate the friction and resistances of the air itself, although the tables on pages 57, 59, and 61 are very suggestive on this point, and theoretical considerations also indicate the great importance of this subject, as will hereafter appear.

RELATION BETWEEN SPEED AND LOAD.

The following table shows the relation between speed and load for various wind wheels:

Table showing the relation between speed and load.

No. of wheel.	Angles of weather.	*A* Turns per minute at maximum.	*B* Turns per minute unloaded.	$\frac{A}{B}$	*C* Load at maximum.	*D* Starting force.	$\frac{C}{D}$	Sail surface.
	°							*Square feet.*
1	35	31.69	59.08	.54	1.65	2.55	.65	9.19
2	35	33.43	57.95	.58	1.85	3.55	.52	18.38
3	24.5, 11.25	47.48	90.48	.52	1.35	2.10	.64	13.59
4	20, 30	55.93	89.43	.63	1.55	3.00	.52	13.59
5	22.5, 32.5	46.10	86.78	.53	1.95	3.4	.57	13.59
6	30	42.10	69.03	.61	1.65	3.1	.53	10.688
7	25	47.40	73.60	.64	1.35	2.5	.54	10.688
8	35	36.84	62.67	.59	1.75	3.25	.54	10.688
9	32.5	34.58	66.40	.52	1.95	3.1	.63	10.688
10	27.5	39.33	72.23	.54	1.75	2.95	.59	10.688
11	20	45.46	77.60	.59	1.35	2.00	.68	10.688
12	15	43.88	75.60	.58	1.15	1.4	.82	10.688
13	40	28.70	56.33	.51	2.15	3.4	.63	10.688
14	45	24.72	48.60	.51	2.15	3.5	.61	10.688
15	47.5	25.30	46.84	.54	1.95	3.65	.53	10.688
16	50	20.67	42.40	.49	2.15	3.60	.60	10.688
17	25, 35	38.70	73.90	.52	1.75	2.75	.64	10.688
18	25	39.42	75.58	.52	1.95	3.1	.63	12.937
19	27.5	38.20	72.26	.529	2.15	3.3	.65	12.937
20	30	39.87	70.78	.56	1.9	3.45	.55	12.937
21	32.5	38.72	67.97	.57	1.9	3.6	.53	12.937
22	35	31.96	64.20	.50	2.1	3.8	.55	12.937
23	25, 30	43.21	73.46	.59	1.75	3.25	.54	12.937
24	27.5	38.87	72.60	.54	1.8	3.4	.53	15.000
25	30	38.95	69.00	.56	1.8	3.6	.50	15.000
26	25	43.74	75.38	.58	1.7	3.15	.54	15.000
27	35	33.74	63.65	.53	2.1	4.0	.53	15.000
28	32.5	34.49	67.07	.51	2.1	3.8	.55	15.000
29	27.5	39.10	73.10	.53	1.9	3.6	.53	17.016
30	30	35.15	69.18	.57	2.1	3.9	.54	I7.016
31	32.5	34.94	66.73	.52	2.1	4.0	.52	17.016
32	35	33.43	62.90	.53	2.1	4.2	.50	17.016
33	25	37.80	75.46	.50	1.9	3.4	.56	17.016
34	25, 35	43.77	76.47	.57	1.7	3.4	.50	12.937
35	27.5	46.64	76.78	.61	1.7	3.3	.52	12.937
36	25	47.05	80.67	.58	1.7	3.0	.57	12.937
37	30	40.41	73.12	.55	1.9	3.5	.54	12.937
38	22.5	52.51	84.65	.62	1.5	2.8	.54	12.937
39	27.5	35.57	64.52	.55	1.9	3.6	.53	13.072

Table showing the relation between speed and load—Continued.

No. of wheel.	Angles of weather.	*A*	*B*	$\frac{A}{B}$	*C*	*D*	$\frac{C}{D}$	Sail surface.
	°	Turns per minute at maximum.	Turns per minute unloaded.		Load at maximum.	Starting force.		*Square feet.*
40	27.5	45.74	82.13	.56	1.9	3.65	.52	12.937
41	25	46.81	84.70	.55	1.9	3.35	.53	12.937
42	30	43.15	77.95	.55	1.9	3.8	.50	12.937
43	25, 30	45.92	84.92	.54	1.9	3.5	.54	12.937
44	25, 30	44.35	84.88	.52	1.9	3.5	.54	13.590
45	20, 30	79.99	156.63	.51	2.9	5.1	.57	14.159
46	17.5, 27.5	85.19	160.90	.52	2.7	4.7	.57	14.159
47	22.5, 32.5	73.31	148.68	.49	3.3	5.9	.56	14.159
48	25, 35	66.79	141.97	.47	3.7	6.4	.58	14.159
49	27.5, 37.5	58.82	136.30	.43	3.9	6.5	.60	14.159

BEST SPEEDS FOR WIND WHEELS.

In the fifth column of the preceding table the decimal fractions $\frac{A}{B}$ indicate for the various wind wheels the ratio of speeds at maximum work to the speed of wheels unloaded.

By consulting the original tables on pages 28 to 46, it may be noticed that there are generally four or five products nearly as great as the maximum product for each wheel. Where the two greatest products are nearly the same, a very slight difference in velocity of wind, or other cause, may make the maximum result correspond to either of two different loads or two different speeds. This may account for certain apparently rather wide variations in the columns $\frac{A}{B}$ and $\frac{C}{D}$.

In general the best speed for most of these wind wheels is about 0.55 of the unloaded speed, and a variation of speed between 0.45 and 0.70 of the unloaded speed will not make a very great difference in the amount of work performed, provided the load is varied to suit the difference in speed.

BEST LOADS FOR WIND WHEELS.

In the eighth column of the preceding table the decimal fractions $\frac{C}{D}$ indicate the ratios of loads at the maximum of work to the greatest loads that the wheels can start without continuous turning.

In collecting from the original tables the numbers *D*, which represent starting forces, the original figures were corrected so as to exclude what was originally added for axial friction. (See "Starting forces" on page 25.) Where 0.3 pound was added to applied loads prior to March 13, 1883, the figures were corrected for *C* in the sixth column

WINDMILL AND RESERVOIR

to correspond to an axial friction of 0.15 pound, as explained under the heading "Corrections for axial friction," page 75.

In general, it may be said that the ratio of best loads to starting forces is about 0.55, and that there may be a variation in the load between 0.50 and 0.65 of the starting force without serious impairment of efficiency.

CONICAL DEFLECTOR IN CENTER OF WHEELS.

Wheel No. 50 was tested because our attention was called to a windmill patent in which a conical deflector was shown. Besides saving the wind that otherwise would pass through the center of wheel unoccupied by sails, an advantage was also claimed because the air was made to act with greater leverage on account of encountering the sails farther from the axis. The experiment showed there could be no possible advantage from such an arrangement.

AIR-CUSHIONED SAIL SURFACES.

When wheel No. 39 was constructed, the narrow strips of board along the edges of the sails were intended not to obstruct the spaces between sails, but to afford air cushions on the faces of the sails against which the wind might act to better advantage than against plain surfaces. It had become apparent that plain sails were decidedly inferior to sails with concave faces, whether circular or angular. (Note experiments with wheels Nos. 40, 43, and 44.)

It was contended by certain windmill experts that the narrow strips added to plain sails, as used in wheel No. 39, would answer the same purpose as the sail forms of wheels Nos. 40, 43, and 44, and that wooden wheels could be more easily constructed in that way. One of the experts had constructed wind wheels similar to wheel 39. It was immediately due to the suggestion of another prominent windmill official that wheel No. 39 was made and tested. For ourselves, we had much more decided opinions after the test than before, notwithstanding the fact that our mathematical solutions as presented in this paper were written out and made public before any of our experiments were commenced. Whatever value there may have been in the air-cushioned sail faces of wheel No. 39, the advantage was more than nullified by the obstruction of spaces between sails and the bad contours of their backs.

OBSTRUCTIONS ON THE BACK OF SAILS.

Our experience with wheel No. 39 suggested that the arms and bands also might be detrimental to the proper smooth and peaceful flow of air between the sails. So we next constructed and tested wheels Nos. 45 to 49, which have no bands and no arms along the backs of the sails. The results, as shown in the table on page 59, speak for themselves.

It may be noticed that wheel No. 47 carried 3.3 pounds as best load, the same as the best load of wheel No. 2, over which it shows a gain in power of about 83 per cent. The gain, therefore, in this case was

entirely in speed. Notice also the ratio between the speeds of the two wheels running unloaded, $\frac{148}{77}:\frac{68}{85}=1.91$. The denominator, 77.85, is taken from the table on page 27.

WASTE OF POWER DUE TO THE ARMS OF WIND WHEELS.

Two or three months after making the many experiments the summary of which is recorded on page 59, it occurred to us that it would be interesting to know and easy to ascertain something definite as to the gain in power effected by the removal of those portions of the arms which usually are made to extend along the backs of sails or between the sails of wind wheels. To represent the portions of arms previously removed, we prepared six pieces of pine wood 1 by 1¼ by 17 inches. These could be quickly attached to the backs of the pasteboard sails by two little screws in each, and as quickly removed, as often as necessary.

We found, on retesting wheel No. 48 in September, that it showed a gain over wheel No. 2 of 84 per cent instead of the 87 per cent gained when tested in June. We attributed this small loss to the drying and warping of the sails, and therefore designated the retested wheel as No. 60. The same wheel, with the six pine strips above mentioned fastened to the backs of the six sails, was designated as wheel No. 61. We found by repeated trials, as usual, that wheel No. 60 required, for the wind velocity taken to produce a maximum product, a load of 1.9 pounds.

This load was the same as the best load for wheel No. 2. The coincidence of best loads made the comparison of wheels No. 60 and No. 2 merely a matter of recording speeds. No time had to be consumed in changing loads and readjustments of the brake, and the two wheels were replaced by each other alternately in rapid succession.

The same method was pursued in comparing wheel No. 60 with wheel No. 61, except that in this case, instead of removing from the axle and replacing the entire wheels, we merely placed and removed in succession the six strips of pine. The table on page 61 gives the averages of results.

It is possible that 1.9 pounds may not have been exactly the best load for wheel No. 61. To facilitate the speed comparisons and render mistakes of brake adjustment impossible, the load was not changed and the adjustment of the brake was left undisturbed during these alternate tests of the two wheels. We consider it altogether probable that an exact determination and application of the best load for wheel No. 61 would not have materially changed the product as recorded. At any rate, simply removing the six strips of pine from the backs of the sails caused an increase in the speed of the wheel with the same load, from 38.13 to 56.50 turns per minute, or 48 per cent.

TWISTED SAILS.

That the angle of weather of a sail should be greatest at the end nearest the axle and least at its outer end where its speed is comparatively great, seems self-evident, and the advantages to be gained by warping or twisting the sails so as to make the weather angles increase as they approach the center have always been recognized, at least in theory, by windmill manufacturers, although comparatively few American wind wheels are made with such sails. Our best results, as shown in the table on page 59, were obtained with warped sails, but it does not appear from previous experiments that the warping was by any means the most important feature of our best wheels.

The tables on pages 51 and 53 afford, in the comparisons of wheels Nos. 34 and 43, having twisted sails, with wheels as nearly like them as possible without twisted sails, an apparent test of the advantages gained by making the weather angles greater at the inner ends of the sails. Judged by these two wheels the advantage is very slight.

We are now satisfied that merely twisting the sails can not do much good for the reason that what is gained in this way by better disposition of the forward or receiving edges of the sails is largely lost by the consequent less advantageous disposition of the rear edges from which the wind escapes.

As we have pointed out in the discussion of the theory of the windmill, the rear edge of a sail should be nearly parallel to the plane of motion without regard to radial distance, while the forward edge should be parallel to the relative direction of the impinging current of air, which depends on radial distance.

This theoretical disposition would make the angles of weather greatest where the sail speed is least, but is a very different thing from the twisting of the sails, as in wheels Nos. 34 and 43.

Fig. 26, on page 61, shows a sail form more nearly in accord with our theory, which makes not only the angle of weather, but also the curvature of the sail, greater with nearer approach to the center of the wheel.

DEFLECTORS IN FRONT OF SAILS.

In our discussion of the theory of the windmill on pages 71 and 72 we have called attention to the fact that our formula (E) indicates that the efficiency of a wind wheel might be increased if the air currents, just before meeting the sails, should be deflected so as to meet the plane of motion at a less angle than 90 degrees. In order to test somewhat this mathematical suggestion, the experiments recorded in the table on page 64 were made. Only a single deflector was used, and that a plane surface. It may be noticed that when placed in front of wheel No. 2 at various angles the deflector caused some increase of speed in every instance, while the load remained the same. But when placed in front of wheel No. 49 its effect as an obstruction overbalanced its value as a deflector.

It did not appear that deflectors would be advantageous in front of the most efficient wheel, nor of sufficient value in connection with the wheel of relatively low efficiency to justify the expense of such cumbersome appliances. We did not, therefore, consider it worth while to experiment further with deflectors.

OBSTRUCTIONS IN FRONT AND IN THE REAR OF WIND WHEELS.

The experiments recorded on page 65 we were prompted to make on account of the contention by certain windmill experts, that an obstruction behind a wind wheel caused about the same loss of power as if placed in front.

Many so-called vaneless windmills had their supporting masts, or tower tops, in front of the wheels, while the ordinary mills with vanes had their supporting masts behind the wheels.

The obstructing boards described under the table on page 65 were intended to represent such obstructions as would be representative of supporting masts placed as indicated. In the case of wheel No. 2, unloaded, the obstruction when placed in front caused a loss of speed amounting to a little more than 3.5 per cent, and when placed behind the loss amounted to a little over 3 per cent.

In the case of wheel No. 49, loaded, the loss of speed from placing the obstruction in front amounted to nearly 14 per cent, and the loss of speed from placing the obstruction behind was nearly 7 per cent.

It may be observed that 3.5 pounds is less than the best load for wheel No. 49 (3.9 pounds), but it should be borne in mind that with all wheels a considerable variation in the load made but little difference with the product when near the maximum.

It might have been profitable if we had extended these experiments. It is evident that obstructions even when relegated to the rear are not obliterated.

MAXIMUM PRODUCTS IN DIFFERENT VELOCITIES OF WIND.

The table on page 66 indicates that maximum products vary as the cubes of the velocities of wind almost as exactly in fact as in theory. If there had been an exact correspondence between the results of experiment and the law of cubes, the figures under $\left(\frac{b}{a}\right)^3$ would exactly equal those opposite under $\frac{B}{A}$. The figures under $\frac{B}{A}$ are in some instances a little greater and sometimes a little less than those opposite under $\left(\frac{b}{a}\right)^3$, as indicated by the plus and minus signs before the differences given under $\frac{B}{A} - \left(\frac{b}{a}\right)^3$. The plus and minus signs happen to be equal in number, showing a remarkable general agreement with the law of cubes. Again, the law of cubes would require that the

numbers under A multiplied by $\left(\frac{b}{a}\right)^3$ should equal the corresponding numbers under B. How nearly the law was actually fulfilled may be seen by comparing the last computed column, $A \times \left(\frac{b}{a}\right)^3$, with the real products of column B.

STARTING FORCES AND LOADS AT THE MAXIMUM IN DIFFERENT VELOCITIES OF WIND.

Under the second table on page 66 we find the conclusion that "starting forces vary as the squares of the velocities of wind." If the law of squares had been strictly confirmed, the computed ratios under $\left(\frac{b}{a}\right)^2$ would have just equaled the actual ratios of experiment as given under $\frac{B}{A}$. The agreement is quite close, but the numbers in column $\frac{B}{A}$ are more often greater than the corresponding numbers in column $\left(\frac{b}{a}\right)^2$. So it appears that starting forces really increase in at least as great a ratio as would conform to the law of squares. But, as we have explained before, it should be remembered that what we have called starting forces could neither be defined nor determined with the same accuracy as was attainable in the case of maximum products. Nor could the loads corresponding to maximum products be determined so accurately as the maximum products themselves, since two or three different loads would generally give about the same product when the product was near the maximum. This fact made it all the more easy to ascertain the maximum products correctly, since a little variation from the best load was compensated for by the consequent variation in the speed of the wheel.

The table on page 77 shows, on the whole, a fairly constant ratio between loads at the maximum and starting forces, from which we may draw the conclusion that loads at the maximum vary as the squares of the velocities of wind.

SPEEDS OF UNLOADED WHEELS IN DIFFERENT VELOCITIES OF WIND.

In the table on page 67 an inspection of columns $\frac{b}{a}$ and $\frac{B}{A}$ will show that in every case but two the counted turns of the unloaded wheel in the higher wind exceeds somewhat the number of turns computed on the supposition that the speed of an unloaded wheel should vary directly as the velocity of wind. The two exceptional cases may be accounted for. We attribute this variation from the natural law in part to the fact, previously discussed, that the axial friction diminishes as the speed increases. Strictly speaking, the wheels, on account of unavoidable friction at the axle, could not be entirely unloaded.

ACTION OF AIR ON THE SAILS OF A WIND WHEEL.

In fig. 31, AB, AB are supposed to represent cross sections of two sails, one following the other as in a wind wheel. DE represents the direction and velocity of the wind with respect to the earth. AE represents the direction and velocity of the sail sections, at right angles to DE. Then DA represents the relative direction of wind with respect to the sails in motion, and the front faces AA of the sails are set parallel to DA. The rear faces of the sails B are set parallel to the plane of the wheel's motion, according to correct theory.

As one sail necessarily follows another in a wind wheel, the air can

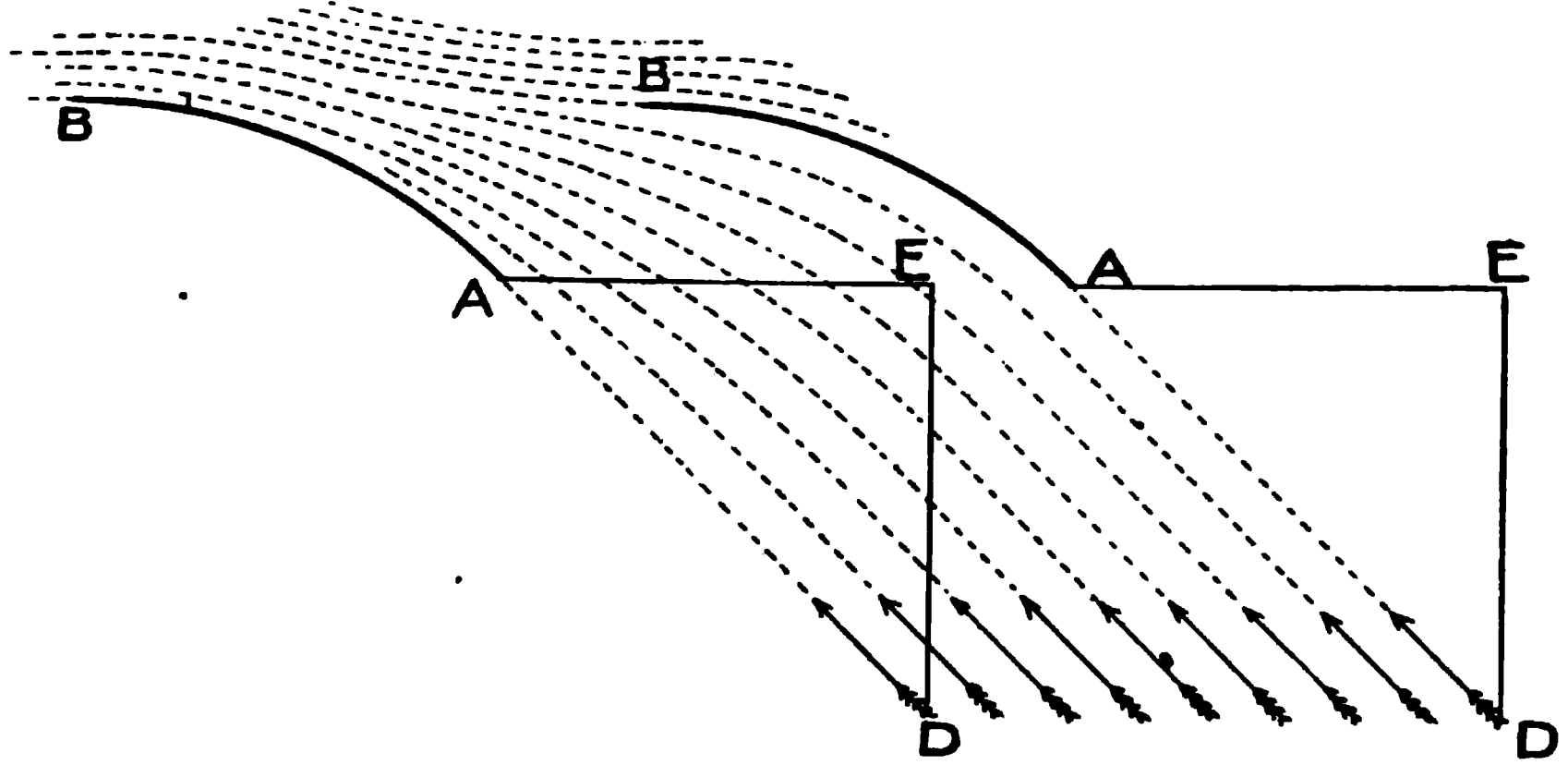

FIG 31.—Action of air on the sails of a wind wheel.

not escape in a direction exactly opposite to the sail's motion, and as the space between sails unavoidably contracts toward the rear edges these edges may in practice conform in some measure to the best possible direction of escape instead of being strictly parallel to the plane of the wheel. The placing of arms on the backs of or between the sails would render a necessary evil worse on account of further contraction of space. Besides, it should be noted that the backs of the sails, as well as their faces, play an important part in deflecting the wind. For it is a well-known fact that air currents cling to and follow the surfaces along which they flow. Therefore, the backs of the sails should be smooth and free from obstructions. It is evident that all the air passing between the sails is deflected and not merely that portion which comes immediately in contact with the faces of the sails. The arrows and dotted lines in the figure indicate the relative direction and deflection of air as it flows through the wheel.

THEORETICAL EFFICIENCY OF THE WIND WHEEL.

Our general formulæ and deductions previously given under theory of the windmill are presented just as they were originally recorded near the beginning of the year 1882. We now see no reason for alter-

ing them in any respect, but there has been so much confusion among mathematical writers on wind action, that we wish to make the matter perfectly clear in its essential points.

It is not necessary to resort to the calculus, nor even to produce the general formulæ (A) and (B) in order to arrive at the theoretical efficiency of a wind wheel. A very simple, graphical solution may be shown as follows: In figs. 32 to 35, AB represents the direction and velocity of the wind with respect to the earth; AC represents the direction and velocity of the sail, a section of which is represented by the curved line CD; the velocity of wind AB is the same for each of the four cases; and the several sail sections are supposed to be taken at the extremity of a sail in fig. 32, at a distance from the center of the wheel equal to two-thirds the radius in fig. 33, at one-third the radial distance in fig. 34, and at one-sixth in fig. 35. We have assumed that

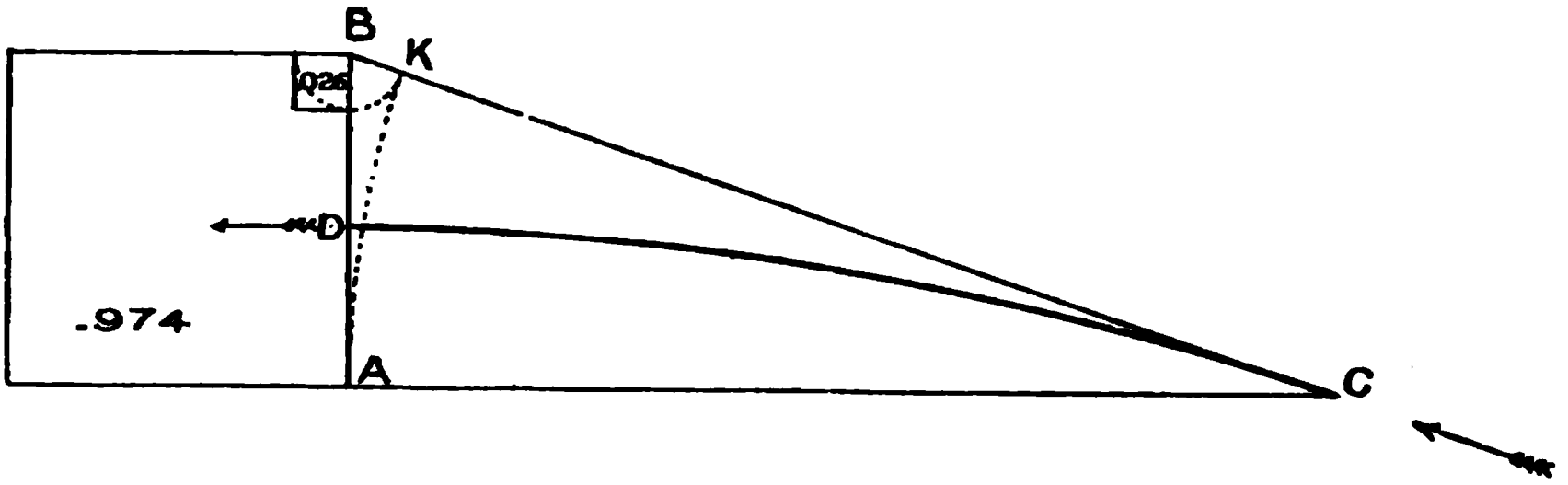

Fig. 32.

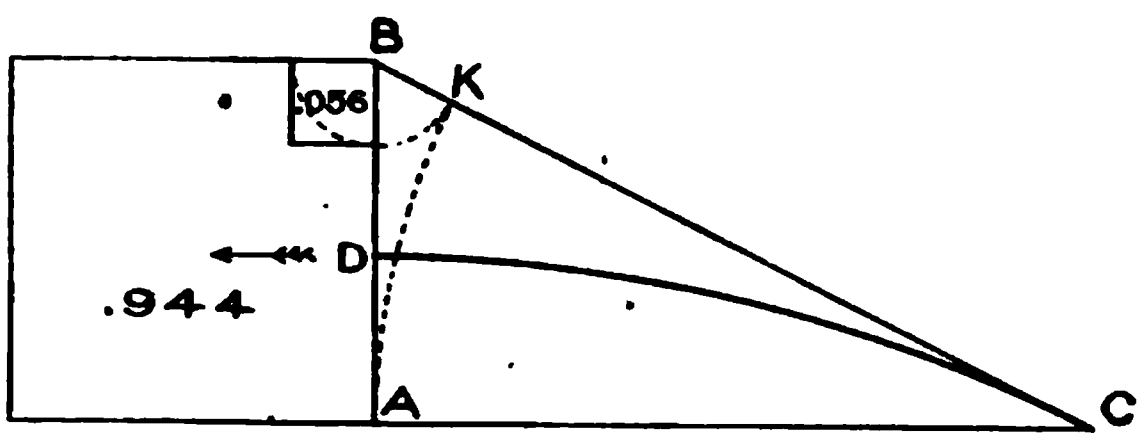

Fig 33.

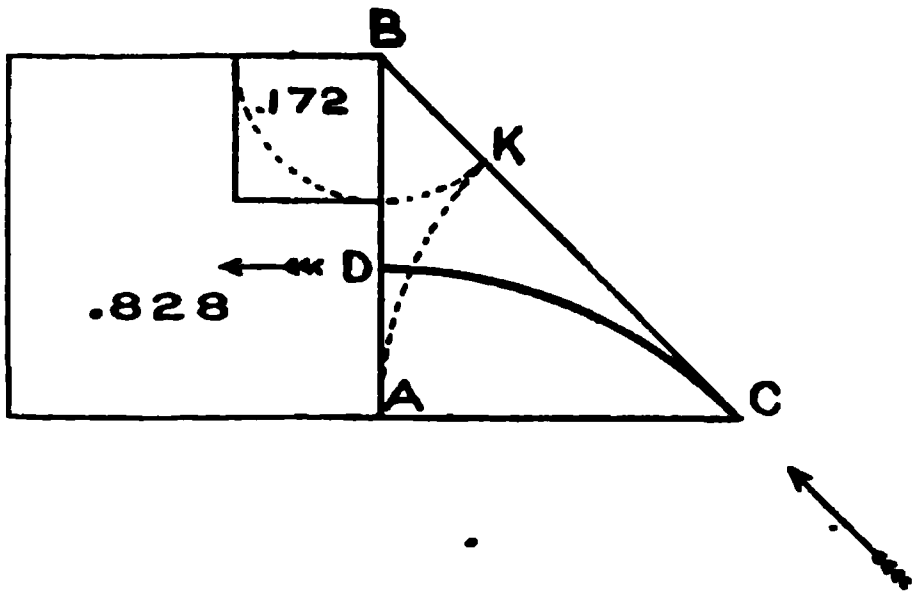

Fig. 34.

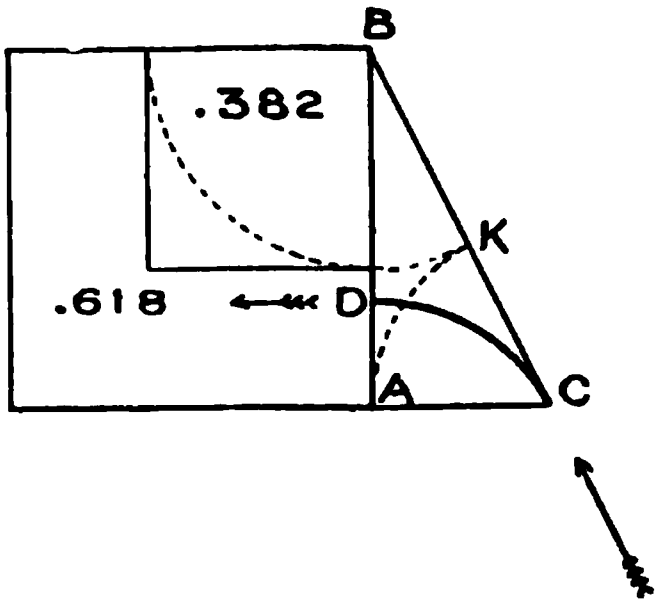

Fig. 35.

FIGS. 32–35.—Theoretical efficiency of the windmill.

the outer extremity of the sail travels three times as fast as the wind. That is to say,

$$AC = 3 \times AB \text{ in fig. 32,}$$

$$AC = 2 \times AB \text{ in fig. 33,}$$

$$AC = 1 \times AB \text{ in fig. 34,}$$

$$AC = \tfrac{1}{2} \times AB \text{ in fig. 35.}$$

CB represents the relative direction and velocity of the wind with respect to the sail in each case. Neglecting friction, the relative velocity of the wind is not changed by contact with the sail. The air escapes from the sail at D with the same relative velocity it had at C; but its course is changed so that it escapes in a direction parallel and opposite to that of the sail's motion. Now, since the sail is traveling with an actual velocity AC in one direction while the air is escaping with a relative velocity CB in the opposite direction, the difference between CB and AC = BK will represent the actual velocity of the air after it has escaped from the sail. The remnant of velocity BK is all there is left of the wind's original motion. The sail has absorbed the rest and converted into work a corresponding amount of energy. A certain quantity of wind started with a velocity AB and gave up all its energy except that corresponding to a velocity BK.

Now, the potential energy of the same quantity of air in motion varies as the square of its velocity, as in the case of any other substance. Hence a square constructed on AB and another square constructed on BK will represent relatively the original potential energy of the wind and the energy it still retains after encountering the sail. These squares are shown in the figures. The small squares represent the waste of energy or that not consumed by the sail. The relative areas of these squares may be readily computed. Taking the large squares as unity the small square equals 0.026 in fig. 32, 0.056 in fig. 33, 0.172 in fig. 34, and 0.382 in fig. 35. The efficiency is represented by the difference between the squares; thus, the efficiency in fig. 32 is 0.974; in fig. 33, 0.944; in fig. 34, 0.828, and in fig. 35, 0.618.

The small squares correspond to the letter k in the formula (B) on page 71. Compare these efficiencies with the values of $1 - k$ as originally obtained by a very different process. There would have been no difference if the decimals had been equally carried out in both cases.

The potential energy of the wind, as well as the useful work resulting from its action on a sail, varies as the cube of its velocity, because the quantity of air coming in contact with the sail increases or diminishes with the change of velocity in the same proportion. It is only when we consider the result of a fixed quantity of air in motion, that its energy varies as the square of velocity and may be represented by square areas as illustrated above.

The work of the same quantity of air varies as the square of velocity, because its resultant reaction against the sail varies directly as the velocity and the sail also travels with the same proportional velocity. If, for instance, 1 pound of air, acting on a sail, has its velocity doubled, the sail travels with double velocity under doubled pressure, so that the work is increased fourfold; and, as in reality the doubling of velocity would cause 2 pounds of natural wind to meet the sail in the same time, the result is doubled again, making it eightfold in theory as well as in practice.

THEORETICAL USEFUL EFFORT OF WIND.

In the figs. 36 to 39, let AB represent the direction and velocity of wind with respect to the earth. In fig. 36 let AC = 3 AB represent the direction and velocity of the outer extremity of a wind wheel; in fig. 37 at two-thirds of the radius from center, AC = 2 AB; in fig. 38 at one-third the radius from center, AC = AB, and in fig. 39 at one-sixth the radius, AC = $\frac{1}{2}$ AB. The circular arc CD in each figure represents correctly what the cross section of the sail at each point should be according to theory. To make the calculation simple and specific, we will consider the action of 1 pound of air only, and that moving at an original velocity of 32.2 feet per second.

We take this particular velocity because it requires the constant action of a 1-pound force to give to 1 pound of air, or to 1 pound of any substance, a velocity of 32.2 feet per second.

To give other velocities to the 1 pound of air, requires the impelling action of a force proportional to the velocity imparted in a second of time. That is to say, the force required to impart to 1 pound of air any velocity, v, is represented in pounds by $\frac{v}{32.2}$.

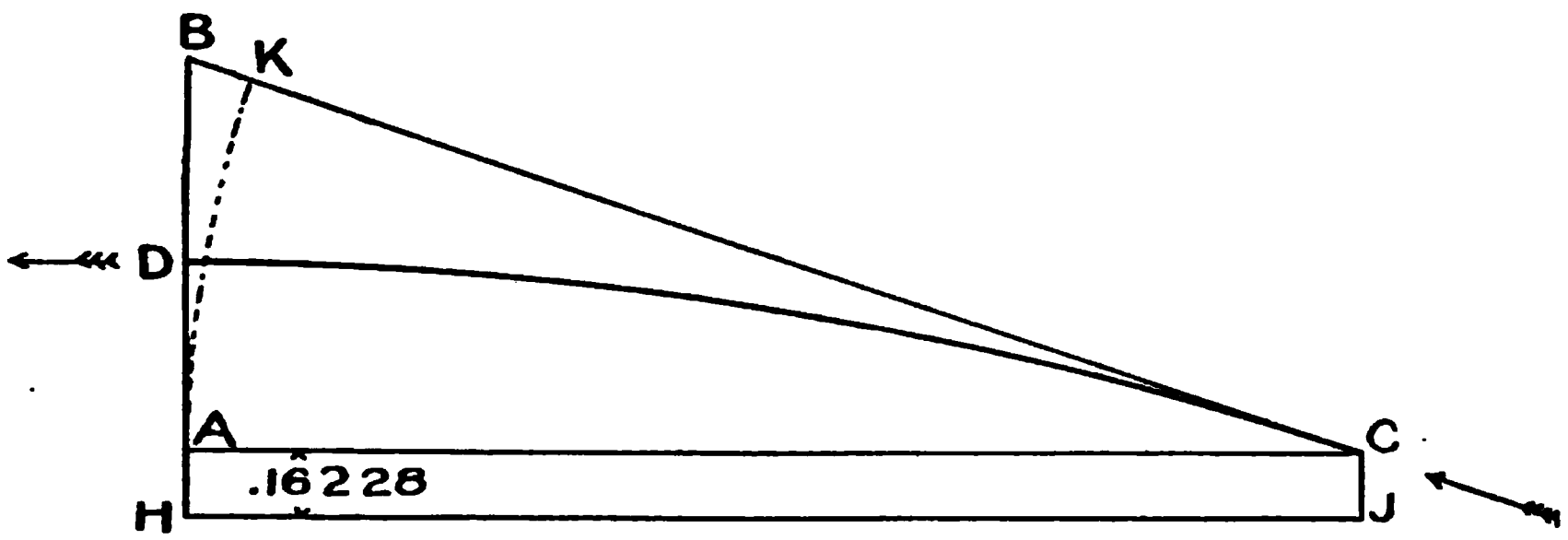

Fig. 36.

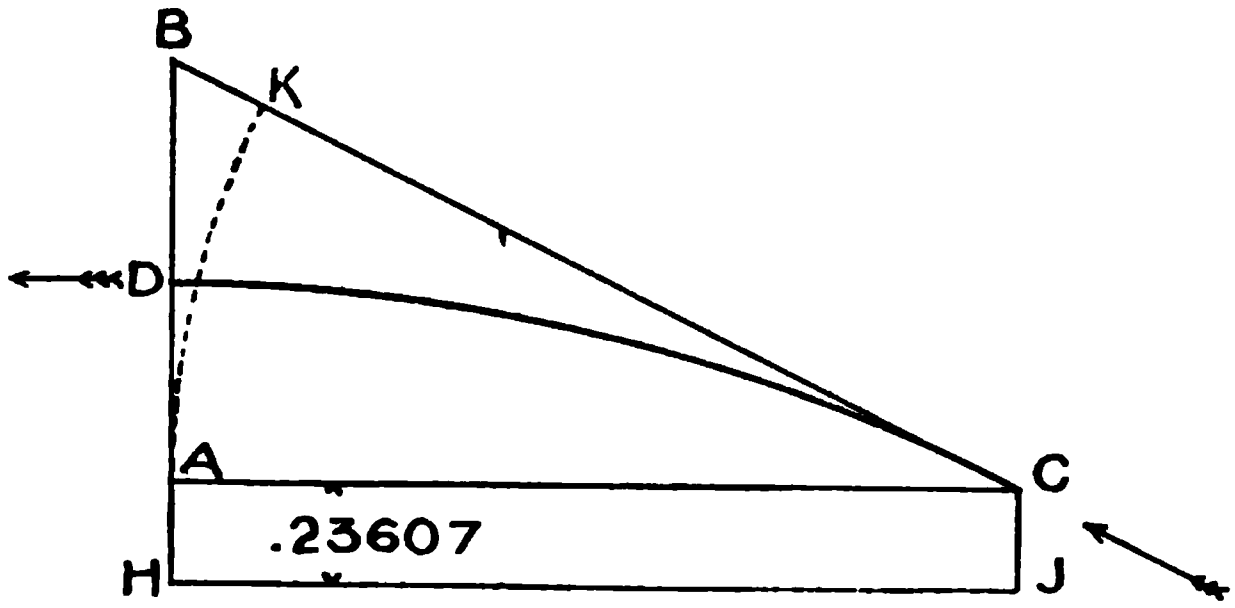

Fig. 37.

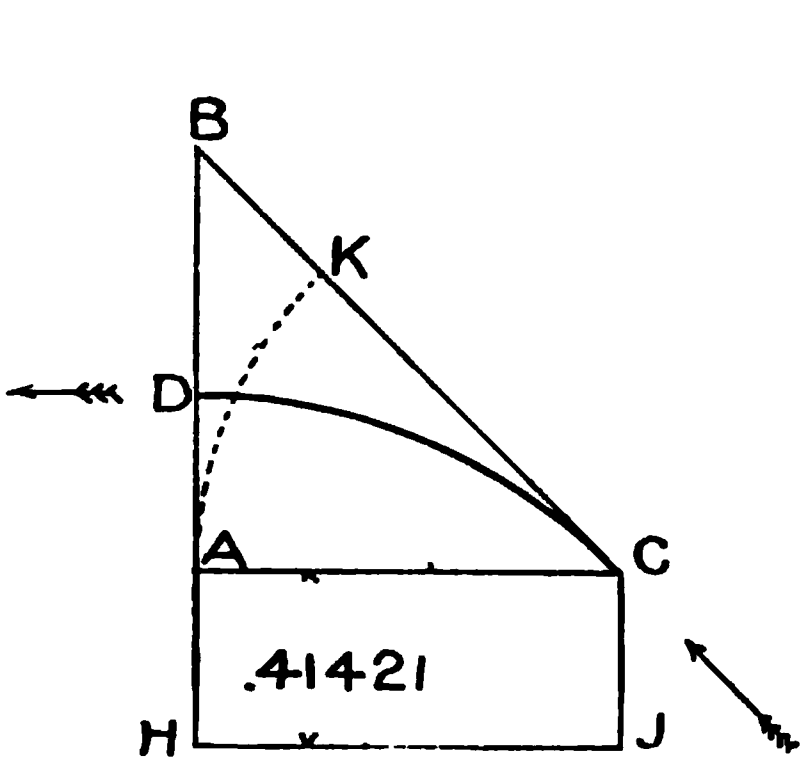

Fig. 38.

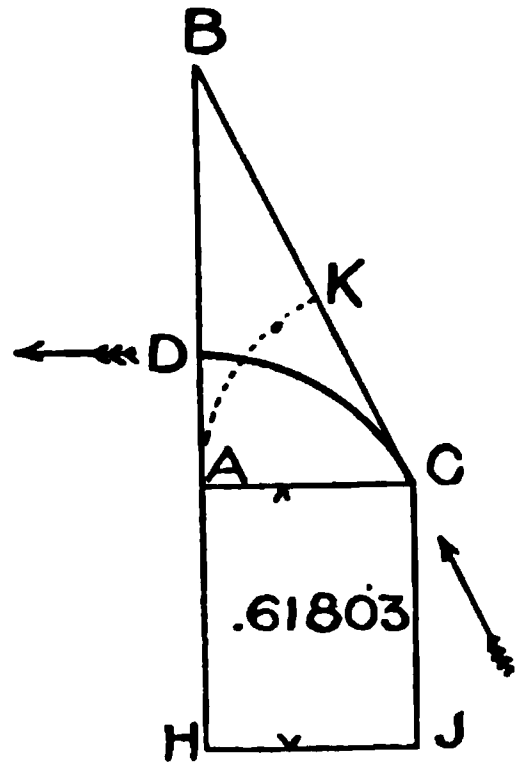

Fig. 39.

FIGS. 36-39.—Theoretical useful effort of wind.

The sail of a wind wheel moves at right angles to the direction of wind or in the direction AC, but the wind meets the sail in motion in the relative direction and with the relative velocity CB, and has with reference to the sail, due to the sail's motion, an opposite motion equal to CA in the direction C to A in addition to its original motion. The length of the line CB represents the velocity with which the air flows along the surface of the sail with undiminished relative velocity, neglecting friction, and the difference between CB and CA, or BK, represents the relative velocity acquired in a second by the air in a direction parallel to CA. That is to say, by action against the sail during one second, the 1 pound of air has acquired a relative velocity BK in a direction parallel to CA, in addition to the relative velocity CA which it had before meeting the sail. This newly acquired relative velocity BK required for its generation a force reacting between the sail and the air proportional to the acceleration of velocity. If BK were equal to 32.2 feet, the reaction would be 1 pound. But the reaction is less than 1 pound in the same ratio that BK is less than AB, which we assumed to be 32.2 feet.

AB:BK:: 1 pound: Useful effort of wind.

So $\frac{BK}{AB}$ represents the ratio between original wind pressure in the

WINDMILL AND RESERVOIR

direction of its original motion and the useful effort which pushes the sail in the direction of its motion. If we lay off on BA prolonged AH=BK and complete the rectangles ACJH, the areas of the four rectangles in figs. 36 to 39, will represent relatively the work theoretically performed in each case. The effort AH may be readily computed. For the action of 1 pound of air, at velocity of 32.2 feet per second, we find that the useful effort is 0.162 pound when the sail moves 3 times as fast as the wind, 0.236 pound when the sail moves twice as fast as the wind, 0.414 pound when the sail moves as fast as the wind, and 0.618 pound when the sail moves one-half as fast as the wind.

AERIAL RESISTANCE TO MOTION.

It should be noted that by far the most striking and important results of our experiments with wind wheels were produced by cutting out from between the sails obstructions which produced aerial resistance to motion; and it should be profitable to study the causes which make these aerial obstructions apparently a matter of greater moment than all the other features of our investigation.

In the two preceding articles we have shown that the greater the sail velocities, theoretically the higher the efficiencies, and also that the useful efforts become smaller as the sail velocities increase.

When the sail travels three times as fast as the wind, the theoretical efficiency is 0.974, very close to perfection; but for a wind velocity of 32.2 feet per second, each pound of air gives a useful effort of only 0.162 pound. It is evident at once that while high sail velocity seems desirable, it does not require great aerial resistance to counteract a large percentage of the useful effort. When the sail travels three times as fast as the the wind, a flat resisting surface of about 1 square inch set perpendicular to the direction of motion would counteract entirely the useful effort due to the action of 1 pound of air. This is computed as follows:

At a velocity of 32.2 feet per second, 1 pound of air per second under ordinary conditions represents a stream of about 59 square inches area in cross section; from which it follows that 59 square inches of flat surface carried normally against still air at the rate of 32.2 feet per second meets with a resistance equal to 1 pound, and at a velocity three times as great meets with a resistance of 9 pounds. But the total useful effort in this case is only 0.162 pound.

Therefore we obtain $F=\frac{59\times 0.162}{9}=1.062$ square inches = flat resisting surface required completely to neutralize all useful effort of wind whose normal pressure against 59 square inches of flat surface equals 1 pound. In like manner we find that F equals 3.418 square inches where the sail velocity is twice the wind velocity, 24.426 square inches where the sail velocity equals the wind velocity, and 145.848 square inches where the sail velocity is one-half the wind velocity.

Or if we let f be the percentage of wind area represented by F, we find that $f=0.018$ when sail velocity is three times wind velocity, 0.059 when sail velocity is twice the wind velocity, 0.414 when sail velocity is equal to wind velocity, and 2.472 when sail velocity is one-half wind velocity.

These percentages hold good for all velocities of wind and emphasize the necessity of reducing to the utmost aerial resistances to motion, if we are to attain high efficiency in a wind wheel.

BEST NUMBER OF SAILS.

An inspection of the table on page 65 shows that wheel No. 35 was more than 3 per cent better than wheel No. 19, although the amounts of sail surface and the angles of weather were the same in both. Wheel No. 35 had exactly the same sails as No. 19, except that each sail of No. 35 contained two of No. 19 placed edge to edge, making 12 broad sails instead of 24 narrow ones. By simply changing the angle of weather from 27.5 degrees to 25 degrees, we made No. 35 into No. 36 and thus gained nearly 6 per cent over No. 19. The wide sails did better with less angle of weather. Wheel No. 6, with the same number of sails as No. 19 but narrower, required a greater angle of weather, 30 degrees.

It is apparent that for a given total of sail area it is better to divide the surface between fewer sails. It may be noted that wheel No. 48, with six sails, gave, in proportion to total sail area, nearly two and a half times the efficiency of No. 2 with 60 sails. Reducing the number of sails reduces the aerial resistance to motion due to the number of edges, and leaves relatively freer interstices for the flow of air between the sails.

BEST RELATIVE AREAS OF SAIL SURFACE.

Tables on pages 47 and 49 give the following results for wheels Nos. 19, 24, and 29:

Effect of area of sail surface on efficiency.

	No. 19.	No. 24.	No. 29.
Square feet of sail surface	12.937	15.000	17.016
Ratio of maximum products (*a*)	1.204	1.212	1.201

a Compared with wheel No. 2.

These three wheels were nearly of the same efficiency. As compared with the area of the zone containing the sails, No. 19 was about three-fourths full, No. 24 was about seven-eighths full, and No. 29 was what we call full, as the total area of the sails about equaled the area of the zone containing them. These wheels all contained the same number of sails set at the same angle, and differed only in width of the sails. It is clear that nothing was gained by making the total sail area more than seven-eighths of the zone, and that very little was

gained by filling beyond three fourths of the zone—surely not enough to pay for the extra material.

From the table on page 65 we obtain the relative values of these three wheels per square foot of sail surface, viz, for No. 19, 0.0931; for No. 24, 0.0808; and for No. 29, 0.0706. Notice also the relative values per square foot of sail surface as given for other wheels in this table.

ACTUAL EFFICIENCY OF THE WIND WHEEL.

To obtain the actual efficiency of wind wheel No. 2, taking the result recorded in the table on page 27, we first obtain the maximum work performed by multiplying the maximum product by the circumference of a circle whose diameter is 2 feet. (See note under the table on page 28.)

62.463 = maximum product in the table.

6.283 feet = circumference of circle 2 feet in diameter.

62.463 × 6.283 = 392.455 foot-pounds per minute = work of wind wheel No. 2 at maximum.

The potential energy of the wind is expressed by the well-known formula $\frac{W v^2}{2 g} = \frac{W}{32.2} \times \frac{v^2}{2}$ in which we make W = weight of air intercepted per second by the total area of the wind wheel. v = velocity of wind in feet per second, and $g = 32.2$, the velocity acquired each second by a body whose motion is not resisted when impelled by a constant force equal to its own weight. The temperature as recorded was 50° F., and on the same day at 2 p. m., in Chicago, the barometer stood at 28.983. Hence 0.075 pound may be taken as the weight of 1 cubic foot of air, 19.635 square feet as the total area of the wheel which was 5 feet in diameter, and 12.286 feet per second, or 8.403 miles per hour, as the velocity of wind. Thus, $W = 19.635 \times 12.286 \times 0.075 = 18.093$ pounds per second, $v^2 = 150.946$, and $\frac{W v^2}{2 g} = \frac{18.093 \times 150.946}{2 \times 32.2} = 42.4078$ foot-pounds per second, or 2544.468 foot-pounds per minute. The portion of actual energy of wind utilized by wind wheel No. 2, or its efficiency, is accordingly $\frac{392.455}{2544.468} = 0.154+$.

To obtain the efficiency of any other wind wheel whose maximum product is directly compared with maximum product of wheel No. 2 as shown in the tables of later date than March 13, 1883, it is only necessary to multiply 0.154, the efficiency of wheel No. 2, by the ratio of products obtainable from the various tables.

For example, in the table on page 59 we find 1.872 given as the ratio of maximum products for wheels No. 48 and No. 2. Hence, 0.154 × 1.872 = 0.288 is the efficiency of wheel No. 48. This is the highest efficiency attained by any of the wheels whose products are recorded in the preceding tables.

WORK OF VARIABLE WIND WITH VARIABLE LOAD.

In most localities the velocity of the wind is exceedingly variable. The average of velocity recorded for an hour by an anemometer gives no idea of the total actual energy of the wind.

It might in conception be actually of uniform velocity, but where the average velocity is 10 miles per hour it is quite as likely to blow one-half the time at the rate of 20 miles and during the other half not at all. The potential energy of 20-mile wind for half an hour is four times as great as that of a uniform 10-mile wind for a whole hour, although the average velocity per hour in each case is the same.

This is taking an extreme case, but it shows how the wind as it blows may and does develop much more energy than could be derived from uniform wind of equal velocity as usually recorded. It would be desirable, if possible, to have the load applied to a wind wheel vary as the square of the velocity of wind, in order that the work might be the greatest possible. Any fixed load which allows the wheel to run freely most of the time is generally altogether too small during much of the time as well as too great at other times. For most uses to which wind wheels are especially adapted an automatic regulation of the load to meet the varying wind would make the best form of wind wheel regulation.

REGULATION OF WIND WHEELS.

Ordinarily wind wheels in this country are made to regulate themselves automatically, so that they can not attain a very rapid rate of rotation. This practice of not allowing the wheel to run at more than a very moderate speed is due to the fact that our wind wheels have been developed mostly in connection with the operation of common reciprocating pumps attached directly to a crank on the shaft of the wheel. Such direct connection necessitates a slow motion of the wheel, in order that the piston speed of the pump may not exceed its economical limit. The consequence is that many wind wheels are allowed to do only a small part of the work which they are capable of developing. Too much attention has been paid to restraining automatically the speed of wind wheels by means which involve a waste of power. So far as the safety of the wheel itself is concerned there should be no need of restraining its speed in any wind under 40 miles per hour; and it should be borne in mind that strains on the wheel, due to any given amount of work, may be diminished in the same ratio that the speed of the wheel is increased.

The gearing of a wind wheel, whether it is geared up or down, should be made to suit the work and the nature of the device through which the power of the wheel is applied to use. When the machine driven requires a high speed of revolution, much gearing up may be avoided if the wind wheel is allowed to revolve rapidly. Back gearing for slow running machines should be resorted to whenever a direct connection

with the machine to be driven will not allow the driven mechanism and the wind wheel both to have their best speeds with reference to work and wind.

For any given velocity of wind the speed of the wind wheel should not change, no matter what the nature of the work or of the machine through which work is performed; but the gearing should be such as to suit the load to the wind.

LIMITATION TO SIZE OF WIND WHEELS ON ACCOUNT OF WEIGHT.

Probably in no other form of motor does a gain in efficiency effect so great a saving in weight as in the wind wheel. The strength of other motors needs to be proportional to their own power. A 4-horsepower steam engine for instance does not need to weigh more than four times as much as a 1-horsepower engine, as the strains to which it is subjected are only four times as great. But a 4-horsepower wind wheel needs to be eight times as heavy as a 1-horsepower wheel in order to resist equally well the violence of exceptional storms. It is the strains of storms, and not its own working strains, that determine the required strength of a wind wheel.

Consider a single sail A supported on the end of an arm fastened to a central spider. Let L = length of the arm from center of wind pressure on sail to point of attachment to spider. If the wind wheel is doubled in diameter, keeping the same proportions, L will be doubled and the area of A will be four times as great. Hence the arm needs to resist four times the wind pressure acting at double the former distance out from its point of attachment, and needs to have eight times its former strength. This eightfold strength is secured by doubling all lineal dimensions, as evidently should be done, when the diameter of a wind wheel is doubled.

But the doubling of all lineal dimensions makes the wheel weigh eight times as much, and as its area is only four times as great, it follows that, in proportion to its power, the weight of the wheel is doubled.

As actually made, all the dimensions of large wind mills do not conform strictly to the proportions of small mills, and often the large wheels are built after different models from small ones. But it is well-known that the large wheels as built do not resist storms so well as small ones, and costly experience has taught manufacturers to make the weight of their large wheels at least approximately what calculation requires.

On account of the disproportionate weight of large wind wheels, the towers which support them also have to be made considerably heavier than would be the case if the large wheels required no more material in proportion to power than do small wheels. If the tower for a large wind wheel were of correspondingly greater height, the weights of towers would follow the same law that should control the weights of wheels.

It is evident that small wind wheels are more efficient in proportion

to weight than large ones, and that the cost of construction, as the wheels are made larger, is increased in much greater proportion than the gain in power.

EFFICIENCY OF WIND WHEELS AS AFFECTED BY DIAMETER.

Another reason why small wind wheels are more efficient than large ones is that the wind meets all parts of the area of a small wheel with greater uniformity of velocity. It needs no special acuteness of observation to discover that the wind strikes different portions of large wheels with great unevenness of velocity.

Before commencing the experiments here recorded we attempted to measure the power of a wind wheel 22 feet in diameter in natural wind. By way of preparation we made a special anemometer, which indicated at sight the velocity of wind. We placed the anemometer as near to the wind wheel as possible, expecting to be able to note where its pointer stood and know the wind velocity for a minute of time, during which the revolutions of the wheel carrying a known load might be counted. The first thing we learned was that the anemometer never pointed steadily to any uniform velocity of wind even for one-fourth of a minute, and we next observed that the anemometer would sometimes almost stop running when the wind wheel showed an extra spurt of speed; also the wind wheel would slow down while the speed of the anemometer was accelerated. We could often hear the wind whistling through the sails on the opposite side of the wind wheel, while very little wind was felt on the near side close to the anemometer. We were unable to obtain a single measurement which we considered worth preservation. We could not determine even the best load for any wind, to say nothing about comparative results. We do not doubt that localities might be found where the wind would blow with greater uniformity, but our experience in trying to measure the power of wind wheels in natural wind led us to provide for artificial wind before proceeding further. The slight variations in the best artificial wind we could command caused a great abundance of vexations, which made the obtaining of accurate average results a matter of tedious labor.

HEIGHT OF TOWERS.

Nothing like steady wind can be obtained near the ground in an inhabited country. Buildings, trees, and other obstructions set the wind to whirling and cause it to flow in sinuous streams of very uneven velocity, concentrated in one place at the expense of another.

There is no effective remedy except in the elevation of the wind wheels several feet at least above all obstructions, even if the obstructions are isolated and a thousand feet away. In order that a large wind wheel may be as efficient in proportion to its area as a small wheel, its height above the ground must be greater. So it is probably not far out of the way to say that the weights of the towers as well as

WINDMILL ON LOW TOWER ON THE GREAT PLAINS.

the weights of the wind wheels, for equal safety and efficiency, should be nearly proportional to the cubes of the diameters of the wheels.

MULTIPLICATION OF WIND POWER.

We have shown that for equal safety in storms the weights of wind wheels of different sizes and like forms should be proportioned to the cubes of their diameters. It would require four 12-foot wheels to equal the area and power of one 24-foot wheel, if the larger wheel is proportionately elevated. But the weight of the one 24-foot wheel would be twice as great as the combined weight of the four 12-foot wheels, and the weight of the one higher tower would probably be twice that of the four shorter towers combined. Hence it would seem that in proportion to the power obtained in each case, the one 24-foot wheel would cost twice as much in material. The thought naturally presents itself that the four 12-foot wheels ought in some way to be combined so as to act in unison for concentrating a great amount of power where it is desirable to use the power at only one point, as in driving one machine of large dimensions. If the four wheels were coupled together rigidly the trouble from uneven reception of wind which is experienced in large wheels would be augmented. The problem has not been worked out, but we may imagine a number of wind wheels, each compressing air according to its own ability and delivering it at any distance into a common reservoir. Natural elevations would be selected as locations for windmills, and such a plant could not be rendered useless for the time by an accident to one or two of the wind wheels. There would necessarily be considerable loss in compressing air, but a low-pressure system might be devised that would greatly reduce the waste. Some waste of power attends every mode of transmission. In seeking to make a gain in power of 100 per cent in proportion to cost of plant, the loss of an extra 25 per cent in transmission might well be tolerated.

There may, however, be other and better methods for accomplishing the object in view than by the means we have ventured to suggest.

POWER OF TWELVE-FOOT WIND WHEEL.

The maximum product of our best experimental wheel, No. 48, is given as 247.123 in the table on page 59, and the velocity of wind as 10.935 miles per hour.

The constant 6.283 multiplied by products gives the foot-pounds of work per minute. Hence $247.123 \times 6.283 = 1552.674$ foot-pounds = work per minute of No. 48 in wind of 10.935 miles per hour.

The work of 5-mile wind compared with the work of 10.935-mile wind is $\left(\frac{5}{10.935}\right)^3$ or .0956. Hence, the work of No. 48 is, in 5-mile wind, $1552.674 \times .0956$ or 148.345 foot-pounds. The work of a 12-foot wheel in 5-mile wind is $148.345 \times \left(\frac{12}{5}\right)^2$ or 854.467 foot-pounds, which is equal to 0.0259 horsepower.

It is, therefore, approximately correct to call the power of a 12-foot wind wheel in 5-mile wind equal to one-fortieth of a horsepower. Computing the power of other wind velocities according to the law of cubes, we obtain for the power of a 12-foot wheel, one-fortieth or 0.025 horsepower in 5-mile wind, 0.2 horsepower in 10-mile wind, 0.675 horsepower in 15-mile wind, 1.6 horsepower in 20-mile wind, 3.125 horsepower in 25-mile wind, 5.4 horsepower in 30-mile wind, 8.575 horsepower in 35-mile wind, and 12.8 horsepower in 40-mile wind.

Most 12-foot wind wheels, as now made, are strong enough to stand the strain of furnishing 13-horsepower, and this we believe is not beyond the actual achievement of some 12-foot wind wheels in 40-mile wind.

VALUE OF MATHEMATICAL FORMULÆ IN EXPERIMENTAL INVESTIGATIONS.

The formulæ which Professor Rankine and other mathematicians have applied to wind wheels give for maximum theoretical efficiency only 50 per cent of the potential energy of the wind actually intercepted by the sails. Our experimental wind wheel No. 48 realized an efficiency of more than 44 per cent, if we consider only the wind which would be intercepted by a surface equal to the projections of the sails on the plane of the wheel. So, if we should accept previous mathematical calculations as correct, we have already made a wind wheel which utilizes 88 per cent of the greatest possible theoretical result, and the remaining 12 per cent margin would not furnish very great incentive to attempts at improvement. Mathematicians hitherto have treated the sails of wind wheels as flat surfaces. Even for flat surfaces their theoretical results have been entirely too small; but it is not our purpose to discuss previous mathematical errors. Wind-wheel sails of proper form are not flat, but curved surfaces, and in analyzing the action of wind on curved sails we have not contradicted Rankine's formulæ, but have confined ourselves to making such suppositions as may be actually true in practice. Rankine's formulæ for the action of fluids on curved vanes give as a theoretical result a maximum efficiency of 100 per cent. This is correct. It shows that we have not made a very efficient wind wheel yet, and affords hope for the attainment of still better results in the future. We know that there is a great waste of energy somewhere, even in the best wind wheels we have been able to produce, but we are encouraged to think that much of the waste can be avoided. We do not claim, therefore, that our experiments have revealed the whole truth. In fact we believe that only a beginning has been made, and fully expect to see our best results greatly surpassed. In our view, the results of our experiments, as here recorded, are far richer in the suggestions offered than in the efficiencies realized.

INDEX.

Page.

Air, resistance of 71, 76, 80, 89
Air currents, action of 84
Air-cushioned sails, description of 57, 79
American wind wheels, development of 19, 30, 74, 75, 92
Anemometer, description of 94
Angle of impingement, theory of 70, 71, 72
Angle of weather, experiments with 22, 75, 90
  Theory of 72
Barometric influences, effect of 27, 72, 76
Brake, automatic adjustment of 27, 67, 68, 69
  Description of 23, 24, 67
Deflector, experiments with 46, 64, 79, 81
  Theory of 71
Dynamometer, description of 23
Efficiency of windmills, determination of ... 22, 60, 91, 96
  Effect of area of sails on 90–91
  Effect of diameter of wheel on 94
  Theory of 69–72, 84–87
Energy of wind. (*See* Wind.)
Experiments with windmills, methods of ... 24, 25, 26, 27, 42
  Place of 9, 21, 22, 72, 73
Friction, corrections for 25, 26, 38, 75–76
Friction brake. (*See* Brake.)
Gearing of windmills, method of 92–93
Journals, friction of 25–26
Loads of windmills, application of 23–24
  Axle friction included in 24, 75
  Determination of best 77–79, 83
  Law of squares for 66, 83
  Regulation of variable 92
Newell, F. H., introduction by 11–18
  Letter of transmittal by 9
Obstructing edges, effect of 90
Obstructions before and behind wheels, effect of 65, 82
Obstructions on sails, effect of 57, 61, 62, 79, 89
Power of wind wheel, determination of 95
Products, determination of maximum 24, 27, 42, 73, 76, 82–83
  Effect of journal friction on 20, 22, 24, 25, 26, 75, 76
  Effect of state of atmosphere on 27, 72, 76

Page.

Regulation of wind wheels, methods of 92–93
Results of experiments, variations in 73
Sail area, determination of best 65, 90–91
Sails, angle of weather of 22, 41, 42, 51, 52, 90
  Effect of twisting of 51, 53, 57, 81
  Efficiency of 85
  Forms of 65, 69, 72, 84, 85, 90
  Inclination of. (*See* Angle of weather.)
  Number of 28, 29, 65, 90
  Obstructions on. (*See* Obstructions.)
  Speed of 59, 71, 89, 93
Smeaton, John, experiments of 19, 20, 21
Speed indicators, forms of 23, 24, 42
Speed of wind wheels, determination of 25, 67, 77, 78, 83, 93
Starting forces, best angles for 40, 41
  Definition and measurement of. 25, 66, 77–79, 83
Thermometric influences, effect of 27, 72, 76
Towers, height and weight of 93–94
Wind, effect of circular motion on 20, 21, 23
  Efficiency and waste of 85
  Energy of 69, 86, 91, 92, 95
  Escaping currents of 69, 71, 72
  Experiments in natural 92, 94
  Impinging currents of 60, 70, 72
  Theory of the action of 69, 72, 84
  Use of artificial 21, 22, 42, 74
  Useful effort of 87–89
Wind wheels, determination of power of .. 95
  Determination of speed of ... 25, 67, 77, 78, 83, 93
  Dimensions of 93–94
  Effect of obstructions on 28, 29, 60, 64, 80
  Efficiency of. (*See* Efficiency.)
  Forms of 19, 20, 30, 74, 75
  Methods of regulation of 92–93
  Reversal of 34, 43
  Sail area for 90
  Size of 93, 94
  Towers for 93–95
Work of wind wheels, computation of ... 24, 91, 95
  Graphic representations of 87, 88
  In variable winds 92
  Law of cubes for 66, 82, 86
  Strains due to 92
  Theoretical formula for 69, 70

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DEPARTMENT OF THE INTERIOR

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CHARLES D. WALCOTT, DIRECTOR

WELLS OF NORTHERN INDIANA

BY

FRANK LEVERETT

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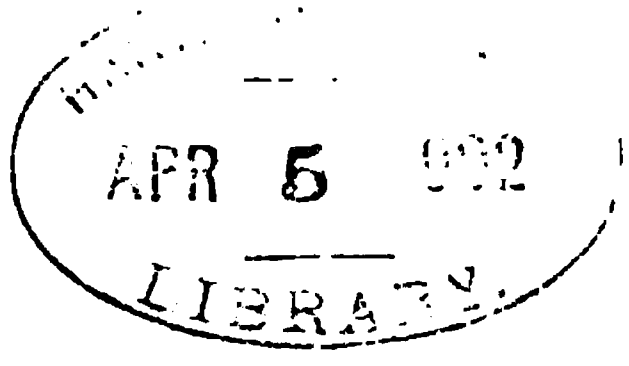

Chas Moore

CONTENTS.

	Page.
Letter of transmittal	7
General statement	9
Detailed discussion of wells	13
Lake County	13
Porter County	15
Laporte County	18
St. Joseph County	21
Elkhart County	23
Lagrange County	25
Steuben County	27
Dekalb County	29
Noble County	31
Kosciusko County	35
Marshall County	37
Starke County	39
Newton County	40
Jasper County	44
Pulaski County	46
Fulton County	46
Whitley County	47
Allen County	48
Adams County	51
Wells County	52
Huntington County	54
Wabash County	55
Miami County	57
Cass County	59
White County	60
Benton County	61
Warren County	66
Tippecanoe County	67
Carroll County	70
Clinton County	71
Howard County	73
Tipton County	75
Grant County	76
Blackford County	77
Jay County	78
Index	81

ILLUSTRATIONS.

PLATE I. Map of Indiana showing the relation of the drift to the ordinary wells 9
II. Map of Indiana showing the Pleistocene deposits 12

LETTER OF TRANSMITTAL.

DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
DIVISION OF HYDROGRAPHY,
Washington, October 20, 1898.

SIR: I have the honor to transmit herewith a report on the wells of Indiana, prepared by Mr. Frank Leverett, assistant geologist of this Survey. This material was brought together by Mr. Leverett in connection with glacial investigations, as noted in the general discussion of the water resources of Indiana and Ohio, published in Part IV of the Eighteenth Annual Report of the Survey, on pages 419–559. Many details were omitted in that publication, as the volume assumed bulky dimensions; but these detailed facts have considerable value and are needed for reference by citizens of Indiana, and it is therefore desirable to make them available by publishing them in the series of Water-Supply and Irrigation Papers.

With these data are presented two maps, one illustrating the distribution of the glacial deposits and the other the relation of the drift to the ordinary wells of the State. These are portions of Plates XXXVI and XXXVII of Part IV of the Eighteenth Annual Report. Their reproduction in connection with this paper is essential to the clear understanding of the descriptive matter.

Very respectfully,

F. H. NEWELL,
Hydrographer in Charge.

Hon. CHARLES D. WALCOTT,
Director United States Geological Survey.

MAP OF INDIANA SHOWING THE RELATION OF THE DRIFT TO THE ORDINARY WELLS

BY FRANK LEVERETT, 1897

WELLS OF NORTHERN INDIANA.[1]

By FRANK LEVERETT.

GENERAL STATEMENT.

The data included in this discussion of Indiana wells were collected mainly during the prosecution of the study of the glacial drift by the writer under the direction of Prof. T. C. Chamberlin. The portion of the State north of the latitude of Terre Haute and Brookville, embracing about two-thirds of the area, has been examined much more thoroughly than the portion south of that line. In the former district nearly every township has been traversed and close attention given to the conditions for obtaining wells. In the latter district only a few hasty trips have been made. Consequently the discussion for the northern two-thirds of the State is much fuller than for the southern third. In addition to material personally collected a considerable amount is taken from reports of the Indiana geological survey, many well sections having been published in those reports. Such material is accredited to the original sources.

A portion of the State, as has long been known, lies outside the glacial boundary. The approximate position of the boundary has been determined in part by Prof. G. F. Wright, in connection with the United States Geological Survey, and in part by members of the Indiana geological survey. Professor Wright's location of the glacial boundary in the southwestern part of the State appears to be less accurate than in the southeastern part. In the former district it has been found by members of the Indiana survey and also by Prof. J. C. Branner to be in places at least 20 miles back from the limits of the drift, but in the latter district the writer's studies have sustained, in the main, the tracing made by Professor Wright, no drift having been noted more than 6 or 8 miles outside his line. The latest results concerning the position of the glacial boundary are embodied in the glacial map of Indiana and Ohio here presented (Pl. I). It will be observed that the boundary lies south of the Ohio River as far west as the vicinity of Louisville, Kentucky. Just above this city it crosses the Ohio and turns abruptly northward, passing through western Clarke, northeastern Washington, central Jackson, and eastern Brown

[1] The length of a single paper in this series being limited by law to 100 pages, it is necessary to divide this paper into two parts and issue them separately. The last part, relating to the southern portion of the State, will be published as Water-Supply and Irrigation Paper No. 26 (in press).

counties, Indiana, a distance of about 50 miles. The course is then westward for about 30 miles, through northern Brown and northern Monroe counties. In northwestern Monroe County it makes an abrupt turn to the south and leads through western Monroe, eastern Greene, western Martin, and northwestern Dubois counties. From southwestern Dubois County the course is south of west across Pike, Gibson, and Posey counties to the extreme southwestern corner of the State.

The average thickness of the drift in the State is estimated to be about 130 feet. It consists of a complex series of sheets, differing widely in age and in structure. These sheets are made known largely by the well sections which appear in this report, for streams and natural exposures seldom reach the bottom of the drift. From a study of the drift sheets of Indiana and neighboring States, the glacial succession has been worked out sufficiently to determine the leading stages of glaciation and deglaciation.

It appears that the sheet which forms the surface of much of the glaciated portion of Illinois, and which is known as the Illinoian drift sheet, is exposed only in a few counties in Indiana, in the southwestern and southeastern portions of the State, the remainder being covered by later deposits of drift. The thickness where this single sheet is exposed to view averages scarcely more than 30 feet, or less than one-fourth the estimated average for the State.

In Illinois and Iowa there is a sheet of glacial drift exposed to view which was apparently deposited contemporaneously with the great silt deposit of the Mississippi Valley, to which the German term *loess* has been applied. This sheet has not yet been identified in Indiana, but the Illinoian drift sheet, where exposed to view, is capped by a deposit of loess-like silt, several feet in thickness, which was in all probability deposited at the time of the loess deposition of the Mississippi Valley and of the correlative drift sheet, which from its development in Iowa is known as the Iowan sheet. The Iowan drift sheet may be present underneath later drift sheets in the northern portion of Indiana.

The next important stage of glaciation has been termed the Wisconsin, chiefly because of its extent and early recognition as a later sheet of drift in the State of that name. It covers the northeastern fourth of Illinois and extends south into Indiana, about to the latitude of Terre Haute and Brookville. The border is somewhat irregular, but departs scarcely more than 20 miles to the north or south of a line leading eastward from Terre Haute to Brookville, the greatest departure being in the western part of the State, where it is deflected northward near the line of the Wabash River about 20 miles. The course of this boundary is indicated on the glacial map (Pl. I). It passes near the towns of Terre Haute, Rockville, Greencastle, Mooresville, Columbus, and Brookville. The loess referred to above covers

the drift to the south of this line, but passes beneath the drift of Wisconsin age to the north of it. In the discussion of counties near this boundary numerous sections are given showing that the Wisconsin drift is much fresher than that which underlies it. The difference in age is known not only by difference in induration of the bowlder clays, but also by the presence of a distinct soil formed on a land surface between the withdrawal of the ice of Illinoian age and the glacial advances which resulted in the deposition of later drift sheets. A soil is found between the Illinoian drift sheet and the capping of loess as well as between the latter and the overlying Wisconsin drift.

From the time the ice sheet occupied the outer border of the Wisconsin drift down to its final withdrawal from the State, it was apparently subjected to considerable oscillation of front and also to a shifting in direction of movement. In the earlier stages the movement was apparently nearly southward across northern Indiana, but in the later stages there was a change to a southwestward movement. There is a growing tendency among the glacialists who are familiar with this region to separate the two movements, giving the name Early Wisconsin to the southward and Late Wisconsin to the southwestward movement.

During the southwestward movement Indiana was covered by ice nearly as far south as during the southward movement, but Illinois was invaded to a comparatively short distance at that stage of glaciation. During this southwestward movement the ice sheet was divided into a series of lobes whose extent and characteristics have been set forth by Chamberlin in the Third Annual Report of this Survey. At the junction of these lobes great interlobate moraines were formed. One of these, occupying the line between the Saginaw and Erie-Maumee lobes, leads from the northeastern corner of Indiana southwestward to Cass County. These interlobate moraines are generally more prominent than those formed at the ends of the lobes. The one just referred to has a few knolls which rise nearly 200 feet above the neighboring basins, though the oscillations in level between knolls and basins are generally less than 50 feet. One of the most prominent moraines formed at the end of an ice lobe is the Valparaiso, situated north of the Kankakee Basin, in northwestern Indiana, and so called from the city of Valparaiso, located on it. It was formed by the Lake Michigan glacier at a time when that glacier extended but little beyond the limits of the shore of Lake Michigan. Another prominent moraine, known as the Maxinkuckee, leads southward from Michigan past South Bend to Lake Maxinkuckee, and thence eastward to join the great interlobate moraine formed between the Saginaw and Erie lobes. It was formed by the Saginaw ice lobe at the time it first became clearly differentiated from the Erie lobe. These and several other moraines are discussed in connection with the well sections which have been sunk in them. Further discussion at this point seems, therefore, unnecessary.

It will be observed that the structure of the drift is intimately related to the position with reference to the ice margin at the time of deposition. Much of the drift deposited under the margin of the ice is a compact, bowlder clay, to which the Scottish term *till* is applied, while that deposited at the end, or carried beyond the ice by waters issuing from it, consists largely of sand and gravel, or if the issuing waters were sluggish the deposits may be of a silty character.

In the discussion of the counties which border the Kankakee marsh attention is called to a deposit of sand which covers the glacial drift. It was formed apparently by a glacial lake which occupied that region for a brief period while the ice sheet was still blocking the Wabash Valley to the south. This lake was long since recognized by Bradley and named Lake Kankakee.[1] A lake formerly extended beyond the present shore of Lake Michigan into the northwestern counties of Indiana, to which the writer has recently applied the name Lake Chicago.[2] It had southwestward discharge, through what is known as the Chicago outlet, into the Des Plaines River and thence to the Illinois and Mississippi. This lake also has left deposits of sand on the counties of Indiana which it covered. In the northeastern part of Indiana there is also an old lake area with well-defined beach lines, occupied by the glacial Lake Maumee,[3] which had southwestward discharge, through the "Fort Wayne outlet," into the Wabash River. This lake bottom is covered less thickly by deposits of sand and silt than the bottoms of Lakes Kankakee and Chicago.

The discussion begins at the northwestern corner of the State, and counties are taken up in order in tiers, the first tier running west to east, the second from east to west, the third from west to east, etc., following nearly the numbering of the counties on the maps. In the case of the southern counties, the data are so meager that they are considered in groups under the head of the immediately subjacent rock formation.

The records of wells here presented should not be understood to indicate the usual depth, for the majority of wells probably are less than 25 feet in depth. They represent the deepest concerning which information could be obtained, and are selected because such wells convey more information con erning the drift structure and its capacity for supplying wells than the shallow ones. The relation of the drift to the ordinary wells is set forth in Pl. II.

The borings for natural gas, which are especially numerous in the central and eastern parts of the State, often throw light upon the structure of the deeper portion of the drift and its water resources where deep water wells have not been made. They also throw considerable light upon the water horizons in the underlying rock strata. Such information as was obtained from the records of these borings is

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[1] Geol. of Illinois, Vol. IV, 1870, pp. 226-229.

[2] Geol. and Nat. Hist. Survey, Chicago Acad. of Sciences, Bull. No. 2, 1897, pp. 64-66.

[3] C. R. Dryer, Sixteenth Ann. Rept. Indiana Geol. Survey, 1888, pp. 107-114.

MAP OF INDIANA SHOWING THE PLEISTOCENE DEPOSITS

BY FRANK LEVERETT, 1897

here presented, though it is not so full as could be desired. In this connection it may be remarked that information concerning water supply in the deeper part of the drift and in the underlying rocks is very meager, compared with the knowledge concerning the surface portion of the drift. Information concerning these deeper beds has been greatly extended since the discovery of natural gas. In many instances borings which failed to obtain gas have been subsequently turned to use because of the water which they yield. Thus a resource which was overlooked in the excitement incident to the discovery of gas is likely to receive proper development in the near future.

DETAILED DISCUSSION OF WELLS.

LAKE COUNTY.

General statement.—Lake County, situated in the extreme northwest corner of Indiana, has for its northern border the shore of Lake Michigan and for its southern border the Kankakee River. It extends eastward from the State line about 16 miles, and has an area of 500 square miles.

The Valparaiso moraine leads west to east across the central portion of the county, and has a width of about 10 miles. It is a somewhat elevated rolling tract, standing 100 to 200 feet higher than Lake Michigan. Wells are sunk to considerable depth, few wells being obtained at less than 25 feet, while many are 50 to 100 feet or more. These wells are obtained usually in beds or pockets of sand or gravel between till sheets.

North of the moraine there is a low plain, much of which was covered by Lake Chicago, the glacial predecessor of Lake Michigan, which had its outlet southwest to the Des Plaines River. For several miles south from the present shore of Lake Michigan the sand deposits of this old lake bottom are so heavy that wells 10 to 40 feet in depth are often obtained without reaching the underlying till. But near the moraine the sand becomes thinner, and is in places but a mere skim coating. On this portion of the plain wells are carried to as great depth as on the moraine, and water is obtained in gravel deposits in the till.

South of the Valparaiso moraine is a narrow strip of gravelly land formed by the waters escaping from the ice at the time it occupied the moraine. On this plain the wells usually obtain their water at depths of 10 to 25 feet, without reaching the bottom of the gravel deposit. Extending several miles north from the Kankakee, in the southern part of the county, there is a marsh too wet for settlement.

The glacial deposits of Lake County are so heavy that wells may be obtained without entering the underlying rock. Borings for artesian water or for natural gas, made at Hammond, Hobart, and Crown Point, penetrate 110, 160, and 176 feet of drift, respectively. From these borings it appears that the drift of this county may have an average thickness of about 150 feet.

Individual wells.—At Hammond many wells are driven to a depth of 10 to 18 feet in sand, entering water at about 8 feet. Filters are used in some cases. Below the sand is a nearly solid bed of blue till, 90 feet in thickness, which contains but little water. At about 110 feet Lockport (often called Niagara) limestone is entered, which furnishes water containing sulphureted hydrogen. The artesian well boring at the distillery, 1,900 feet in depth, is discussed elsewhere.[1]

At Whiting a portion of the water supply is furnished by shallow wells in the beach sand, 20 feet or less in depth. A portion of the water supply is pumped from Lake Michigan by the Standard Oil Company and made use of by many families.

The villages of Gibson, Hessville, Tolleston, Liverpool, and Lake all depend upon shallow wells driven or dug to a depth of 10 to 40 feet in the surface sand. In some cases contamination is liable to occur from privy vaults and other sources.

At Hobart the wells 15 to 25 feet in depth usually penetrate a few feet of clay, which probably prevents contamination of water. A well at Owens's brickyard reaches the underlying rock and has the following section:

	Feet.
Yellow silt, pebbleless, calcareous	10
Blue silt, pebbleless, calcareous	50
Blue till, hard and stony	97
Hard rock	3
Total	160

Mr. Leavenworth's well, 3 miles west of Hobart, depth 80 feet, is above the limits of the lake deposit and is mainly through blue till. Several wells in that vicinity 50 to 100 feet deep do not reach the bottom of the drift.

Wells in the vicinity of Ainsworth, on the north slope of the Valparaiso moraine, often exceed 50 feet. After penetrating yellow till 10 or 12 feet they are mainly through blue till.

In the vicinity of Crown Point, near the crest of the Valparaiso moraine, there are several tubular wells 75 or 80 feet in depth, mainly through blue till.

Tubular wells in the vicinity of St. John, near the crest of the moraine, obtain water at 50 to 100 feet in sand beds included in the till.

Wells on the south slope of the Valparaiso moraine usually enter a water-bearing sand or gravel after penetrating a few feet of till, water being more easily obtained there than on the crest or north slope.

A well at the powder factory, 1 mile west of Miller Station, in the northern part of the county, 75 feet in depth, entered a bed of molluscan shells at the bottom of the sand, 40 feet below the surface and probably several feet above the level of Lake Michigan. Below the shells a bluish silt or fine sand is penetrated 35 feet.

[1] See Eighteenth Ann. Rept. U. S. Geol. Survey, 1896-97, Part IV, 1897, p. 489.

PORTER COUNTY.

General statement.—Porter County is situated just east of Lake County, and has Lake Michigan for its northern and the Kankakee River for its southern border. It is 15 miles in breadth, 25 to 30 miles in length, and has an area of 410 square miles.

The Valparaiso moraine traverses the county from southwest to northeast, slightly north of the center, and has a width of about 8 miles. It reaches a higher elevation in this county than in Lake, some points being fully 250 feet above Lake Michigan. It includes several lakes, one of which furnishes the water supply for Valparaiso, the county seat. In the western portion of the county till predominates as far as wells penetrate—150 to 200 feet. But in the eastern portion of the county, where the moraine reaches its highest elevation, it contains a large amount of dry sand and gravel, and strong wells are obtained only by penetrating to a depth of 100 to 160 feet.

Extending north from the moraine there is a low plain reaching to the Calumet River, which is underlain, as a rule, by till, but is coated quite generally with sand. In this plain wells vary greatly in depth, but are usually 20 to 40 feet.

North of the Calumet River there is a narrow ridge of till forming a feeble morainic belt. Its width seldom exceeds 1 mile and its relief is but 30 to 50 feet. Along this ridge wells are frequently 75 to 125 feet in depth, it being one of the most difficult places in the county to obtain water.

North of this till ridge there are heavy deposits of lake sand, rendering a portion of the district a barren waste. The sand is drifted by the wind into dunes 100 to 200 feet in height. This belt, however, occupies only a breadth of 2 or 3 miles, though extending the entire width of the county. This district is largely uninhabited. In the farms along its border next the till ridge wells usually obtain water before reaching the bottom of the sand at depths of 25 to 50 feet.

South of the Valparaiso moraine the formations are like those of Lake County, there being a gravel plain several miles in width, extending on the south into the uninhabited Kankakee marsh. The moraine extends spurs out into this gravel plain nearly to the borders of the marsh.

The glacial deposits of this county, like those of Lake, are so heavy that wells obtain water without entering the underlying rock. Borings for natural gas made at Valparaiso, Hebron, and Boone Grove penetrate 126, 108, and 140 feet of drift, respectively, while a boring for an artesian well in the northeast part of the county has 245 feet of drift. It appears from these borings that the average thickness of the drift in this county may slightly exceed 150 feet. Several wells along the Valparaiso moraine, as indicated below, reach a depth of over 150 feet without entering rock.

Individual wells.—The Blair artesian well, in the extreme northeast corner of the county (sec. 1, T. 37, R. 5 W.), has the following section:

	Feet.
1. Sand with peaty beds near bottom	30
2. Adhesive blue clay with thin sand beds	55
3. Gravel and sand with water	9
4. Blue clay like No. 2	110
5. Gravel with water	6
6. Blue clay like No. 2	35
7. Shale (?)	1
8. Hard gray limestone	180
9. Soft rock, subject to caving in places	66
10. Hard limestone	372
Total	864

The well mouth is about 20 feet above Lake Michigan, or 600 feet above tide. Flows occur at 68, 72, 78, 80, 85, 95, and about 200 feet in the drift. The flows were weak until a depth of about 85 feet was reached, when a strong flow with head 18 feet above the surface was obtained. The flow from 200 feet is also strong. The water from all the veins in the drift is fresh and of good quality. At a depth of 370 feet sulphur water was struck, which gradually increased in strength in the next 150 feet. The head is, however, 10 feet lower than that from the drift deposits. The combined flow is about 400 barrels per hour and the temperature 62° F.

At Furnessville, on a beach line in the north part of the county, a well 80 feet in depth penetrated beach sand 25 feet, at the base of which logs were encountered. Below the logs is a blue clay, probably till, which was penetrated about 50 feet when a water-bearing sand and gravel was struck.

A well on the beach line immediately north of Calumet River, near the east line of the county, obtains water at the base of the beach sand at 23 feet. Neighboring wells south of the beach line enter a blue clay, nearly pebbleless, at 3 to 5 feet, and in some cases penetrate this to a depth of 50 feet before obtaining water.

At Chesterton and Hageman, in the northern part of the county, wells are seldom more than 20 feet in depth, and usually obtain water at 10 or 12 feet. As they are mainly through sand, there is danger of contamination.

Records of several wells were obtained along the till ridge north of Calumet River, near Chesterton. They penetrate yellow till 18 or 20 feet, below which is a blue till, hard and stony, which is usually penetrated 40 or 50 feet before a water-bearing sand or gravel can be obtained. In one well a dry sand, 15 or 20 feet in thickness, was found between the yellow and blue tills, and the blue till there afforded no water until it had been penetrated 70 feet. The depth of the well is 125 feet.

From the Calumet River south to the Valparaiso moraine water is usually obtained at 8 to 25 feet. In some cases surface clay a few feet in depth is penetrated, but quite as often the wells are almost entirely in sand or gravel. In the western part of the county, however, in the vicinity of Wheeler and northward for 4 or 5 miles, this plain is underlain by a compact till, and wells are in some places difficult to obtain. There is a small till ridge leading north from Wheeler, on which it is especially difficult to obtain wells. Several borings have been made along the ridge to a depth of 100 to 200 feet. In one case a boring was abandoned at 200 feet without obtaining water. In another case water was obtained after penetrating 155 feet of till. Another well found water after penetrating 115 feet of till. A plain known as Twenty Mile Prairie, lying north and east of the till ridge just mentioned, is underlain by a very fine sand, so that wells have been carried to a depth of 150 feet before entering coarse sand or gravel. On this prairie there is usually:

	Feet.
1. Yellow till	7 to 10
2. Blue till	20
3. Fine gray quicksand	75 to 125

Passing to the Valparaiso moraine, we find in the western part of the county a region in which strong wells are difficult to obtain, except in a few favored localities, there being a very compact till, similar to that on the plain north of the moraine. At Smalls Crossing, 3 miles southwest of Wheeler, a well penetrates the following beds:

	Feet.
1. Yellow till	8 to 10
2. Blue till	35 to 40
3. A fine sandy deposit, in places resembling till	150
4. Coarse water-bearing sand	19
Total	219

Mr. Currier's well, 1 mile south of Wheeler, in which no good vein of water was found, penetrates—

	Feet.
1. Yellow till	15
2. Blue till, soft	140
3. Blue till, hard	39
Total	194

On the south slope of the moraine in the western part of the county, water-bearing sand or gravel is usually found at about 40 or 50 feet.

Following the moraine northeastward to Valparaiso, the till is found to give place in its lower portion to beds of sand and gravel. In the southern part of Valparaiso, and also for some distance south of the city, wells often obtain water at a depth of 25 feet. Occasional deeper wells in that district show a large amount of coarse sand or fine gravel below a few feet of surface till. On the elevated ground in the north-

The artesian well at the penitentiary, 1 mile west of Michigan City, has the following section reported by Dr. Levette:[1]

	Feet.
1. Surface sand	48
2. Clay	4
3. Sand	24
4. Clay	66
5. Sand	30
6. Marcellus shale	76
7. Upper Silurian limestone, with fossils	293½
Total	541½

The boring is reported to terminate in a porous limestone rock which furnishes a flow of water strongly impregnated with sulphureted hydrogen. Its head is 22 feet above the surface of the ground; rate of discharge about 300 gallons per minute; temperature, 57° F. The well mouth being about 18 feet above the level of Lake Michigan, or 600 feet above tide, the head at this well is 622 feet above tide.

A remarkable instance of the rise of water in a sand dune above lake level, was found at the Yankee Slide, a dune on the shore of Lake Michigan, in the west part of Michigan City. Wells on its slope, at an altitude of 40 or 50 feet above the lake, obtain water at a depth of but 12 feet.

The wells on the low plain in northwestern Laporte County, and also on the till ridges which traverse that plain, show a preponderance of till. The water-bearing sand and gravel appears to be in local deposits or sheets of limited extent. Neighboring wells often have very dissimilar sections. In some a sand or gravel bed appears, which is absent in others; some show a solid bed of till to a depth of 75 or 100 feet, while others present alternations of till with sand or gravel. The deepest well record obtained on this plain is that at a farmhouse 4½ miles south of Michigan City, and is as follows:

	Feet.
1. Yellow till	20
2. Dry sand	8 to 10
3. Blue till	85 to 90
4. Sand	50
Total	165

There are beach lines traversing this plain immediately south and east from Michigan City, on which wells are sometimes obtained at depths of 12 to 16 feet without reaching the bottom of the beach deposits.

On the north slope of the Valparaiso moraine, near the west line of the county, and just south of the Lake Shore and Michigan Southern Railway, a well 148 feet in depth enters dry sand below till at about

[1] Fifth Ann. Rept. Indiana Geol. Survey, 1873, pp. 470-471.

20 feet, which continues to the water-bearing sand and gravel near the bottom. Occasional deep wells along this moraine show that sand and gravel, as in the above section, greatly preponderate over the till. As a rule, however, wells are obtained along the moraine without penetrating to greater depth than 50 feet.

Wells on the gravel plain, south of the moraine, are usually obtained at 10 to 20 feet. Several villages situated on this gravel plain depend upon these shallow wells for drinking water, though the water appears liable to contamination.

The gas-well boring near Lacrosse, in the southern part of the county, enters water in gravel 5 feet below the surface, and wells in that vicinity are only 10 to 17 feet in depth. The boring was carried to a depth of 838 feet, but water does not rise above the surface, which is 675 feet above tide. The well is used for watering stock.

ST. JOSEPH COUNTY.

General statement.—St. Joseph County is situated east of Laporte, about midway of the north boundary of the State. Its area is 470 square miles. About one-half the county is a gravel plain formed by the outwash from the ice sheet. In the northwestern portion of the county the outwash is from the Valparaiso moraine, and the plain descends from about 800 feet at the border of the moraine to 725 feet at the border of the Kankakee marsh. In the southwestern portion of the county the outwash is westward from the Maxinkuckee moraine of the Saginaw lobe, and there is a similar descent from the moraine to the Kankakee marsh. In the northeastern portion of the county there is an extensive gravel plain along the St. Joseph River, whose head is in southern Michigan in a later moraine of the Saginaw lobe. The southeastern part of the county is occupied by a till plain which borders the Maxinkuckee moraine on the east. The Maxinkuckee moraine passes diagonally across the county from the southwest to the north border and has a width of about 5 miles. It is interrupted by a gap at the St. Joseph River near South Bend 2 or 3 miles in width. The highest portions of this moraine stand fully 300 feet above Lake Michigan, or about 900 feet above tide.

Very little is known concerning the thickness of the glacial deposits, there being, so far as the writer is aware, but one point within the county where rock has been struck. A gas boring at South Bend, in the valley of St. Joseph River, has 137 feet of drift. Its altitude is but 725 feet above tide, or fully 150 feet lower than the uplands of the southeastern portion of the county. If, therefore, the rock surface has a general level as low as at South Bend, the drift of the county would be from 120 to 300 feet in thickness, with an average of perhaps 200 feet.

Individual wells.—The gas-well boring at South Bend is reported by Dr. Phinney[1] as follows:

	Feet.
1. Sand	25
2. Gravel	20
3. Clay	30
4. Sand	25
5. Gravel	37
6. Shales	238
7. Limestone	805
8. Limestones and shales	220
9. Utica shale	185
10. Trenton limestone	85
Total	1,670

Salt water was struck at 375 and 610 feet, and also in the Trenton at 1,670 feet. From the latter horizon it rose within 200 feet of the surface.

The city of South Bend obtains its water supply from about 30 flowing wells, situated along the valley of the St. Joseph River. The wells have a depth of 100 to 125 feet, with an average of about 110 feet. They are obtained in gravel beneath a bed of clay 20 to 40 feet in thickness, which acts as a cover and prevents contamination of the water. This clay is probably a water deposit rather than a glacial deposit, as it is described as entirely free from pebbles of any kind. The head is sufficient to carry the water above the surface only on the low ground along the river bottom, about 670 feet above tide. The gravel plain on which the city was built stands 20 to 30 feet or more above the height to which the water will rise.

The private wells in South Bend are often obtained without penetrating a bed of clay, and the ground water is usually at sufficient height to easily receive the leaching from cesspools. Such wells may become a source of danger to the health of the city.

Wells in the city of Mishawaka are also situated on a gravel plain, and are usually about 20 feet in depth, and the water stands within 12 feet of the surface. There appear in the majority of cases to be no beds of clay or other impervious material to prevent contamination of the water from cesspools. The St. Joseph River, drawn upon for fire protection and irrigation, might easily be made to furnish the supply for domestic use.

Wells on Portage Prairie, a gravel plain in the northwest part of the county, are usually 60 or 80 feet, and seldom less than 40 feet, in depth. A well on this prairie, at Mr. Womer's, near the State line, 174 feet in depth, has the following section:

	Feet.
1. Sand and gravel, with water near bottom	67
2. Blue clay and blue quicksand	99
3. Gravel and sand, with water	8
Total	174

[1] Eleventh Ann. Rept. U. S. Geol. Survey, 1889-90, Part I, 1891, p. 734.

Wells on the gravel plain west of the Maxinkuckee moraine, near North Liberty, usually enter clay below the gravel at about 20 feet. Two wells in the Potato Creek valley, east of North Liberty, obtain flows of water from depths of 45 and 70 feet.

Wells at Walkerton, also on the gravel plain, obtain water at 20 or 30 feet. The water surface is usually nearly 20 feet from the mouth of the well, but even this depth is not sufficient to insure freedom from contamination, there being no impervious stratum above the water vein.

A well on the gravel plain between Walkerton and North Liberty, in sec. 5, T. 35, R. 1 E., 160 feet in depth, is mainly through sand and gravel. The water rises nearly to the surface. Wells in that vicinity usually obtain water at 10 to 20 feet. One well near Walkerton, however, failing to obtain water in the surface gravel, passed through a pebbleless blue clay 50 feet in thickness, obtaining water at a depth of 70 or 80 feet.

Records of two deep wells were obtained on the Maxinkuckee moraine, about 8 miles south of South Bend, in sec. 17, T. 36, R. 2 E. One at Mr. Sweeney's, 131 feet in depth, after penetrating 22 feet of yellow till, passes through alternations of sand and blue till for about 100 feet before reaching the coarse gravel. The other well, at Mr. McClelland's, has a similar section and is 146 feet in depth.

On the plain east from the Maxinkuckee moraine many wells are but 15 to 20 feet in depth, and enter sand or gravel below till near the bottom. A few tubular wells are 80 or 100 feet in depth.

ELKHART COUNTY.

General statement.—Elkhart County is situated immediately east of St. Joseph County, on the north boundary of the State, and has an area of 470 square miles. Like St. Joseph County, a large portion of its surface is a gravel plain. The most extensive gravel plain is that along the St. Joseph River, in the northwest part of the county, which comprises an area of more than 100 square miles. There is also a gravel plain along the Elkhart River from the southeast corner of the county northwestward to the St. Joseph gravel plain. From the Elkhart gravel plain there are extensions southward into Kosciusko County, past New Paris and Milford, and southeastward into Noble County near Cromwell. This system of gravel plains comprises an area of fully 100 square miles. There is also a narrow gravel plain along Little Elkhart River, in the northeast part of the county. About half the county is, therefore, embraced in the gravel plains. The uplands consist of a till plain having an area of about 125 square miles, situated in the southwest part of the county, and of morainic belts, with small areas of nearly plain surface, occupying an area of about 150 square miles in the eastern and southern parts of the county. The altitude of the gravel plains is mainly below the 800-foot

contour. The uplands are mainly between 800 and 900 feet above tide, though small areas on the moraines in the eastern and northeastern parts of the county rise above 900 feet.

The thickness of the drift is known at three points—Elkhart and Goshen, and near New Paris, where it is 122, 162, and 90 feet, respectively. Should the rock surface of the entire county be as low as at these wells, the thickness of the drift would average fully 200 feet.

Individual wells.—At Elkhart the majority of wells are about 30 feet in depth. They penetrate sand and gravel for 20 feet or more, when a thin bed of clay is usually found as a cover for the water-bearing gravel. The mayor reports that he considers the clay a protection against contamination.

A few wells in Elkhart have been put down to a depth of 100 to 120 feet, which have sufficient head to overflow on the low ground near the streams. They penetrate usually a large amount of blue clay, and obtain water in a coarse gravel or cobble near the base of the drift. The water from these flowing wells is chalybeate.

At Goshen the city water supply is from a large well, 34 feet in depth and 30 feet in diameter. After penetrating a few feet of surface sand, it passes through 19 feet of blue clay, which is thought to insure its freedom from contamination. The water is obtained from a coarse sand beneath the blue clay. Its head is sufficient to bring it to the level of the well mouth.

One of the gas-well borings at Goshen was carried only to the Lockport limestone, where salt water was struck which rose to the surface. Another gas-well boring in that city was carried to a depth of 239 feet into the Trenton (Phinney). So far as known no use is made of the water from either of these wells.

In the vicinity of Middlebury, in the eastern part of the county, on the elevated portions of the moraine, tubular wells are usually 80 or 100 feet deep and penetrate a large amount of till.

A well on the border of the St. Joseph gravel plain in the northeast part of the county, in sec. 27, T. 38, R. 7 E., is mainly through gravel to a depth of 65 feet. Wells on this plain are usually but 15 or 20 feet.

Near New Paris, on the border of a morainic ridge, one well penetrates till to a depth of 110 feet, another, 1 mile north, 102 feet in depth, is mainly in sand and gravel. It is thought to have struck rock at about 90 feet. The morainic tracts in that vicinity usually contain more gravel and sand than till. Knolls are often composed largely of gravel. In the eastern and northeastern part of the county the morainic tracts contain a larger proportion of till.

The upland plain in the southwestern portion of the county is a continuation of the plain of southeastern St. Joseph County, and its wells have similar depth and structure, being through till for a distance of 20 or 25 feet, when a water-bearing sand or gravel is struck.

In some cases wells are obtained at about 10 feet in a bed of sand or gravel between the yellow and blue till. A few tubular wells have been sunk to a depth of 80 or 100 feet to a water-bearing sand or gravel below a sheet of blue till.

LAGRANGE COUNTY.

General statement.—Lagrange County is situated immediately east of Elkhart, on the north boundary of the State, and has an area of 384 square miles. It is one of the most elevated counties in the State, the greater part of its surface being above the 900-foot contour, while several tracts in the eastern part of the county, aggregating an area of perhaps 75 square miles, stand above the 1,000-foot contour. It has several small morainic belts, formed by the Saginaw lobe during its recession. It has also conspicuous morainic hills in its northwestern corner and on the eastern border of the county. There is one extensive gravel plain in the county, traversed by Pigeon River. It lies on the southwest border of a prominent Saginaw moraine, which occupies northeastern Lagrange County and passes northwestward into Michigan. This plain has a breadth of 2 to 6 miles and traverses nearly the entire width of the county, a distance of over 20 miles. Aside from this main gravel plain there are small areas underlain by gravel, one of which, known as the Haw patch, covers several square miles on the southern boundary of the county; another borders the Little Elkhart River in the western part of the county.

So far as known to the writer, the bottom of the drift has been reached by only one boring in this county, though it has been penetrated to a depth of 200 feet in several wells, and there are numerous wells 100 feet or more in depth. It is thought by Dr. C. R. Dryer[1] that a farm well in southwestern Lagrange County may enter black shale at 150 feet.

Individual wells.—On the strong morainic belt in the northwest part of the county the sharpest knolls are usually made up of gravel and sand, but those of gentler contour often contain till. The wells vary greatly in depth, some being but 15 or 20 feet, while others are 50 to 75 or more. On the overwash gravel plain south of this moraine wells are obtained in gravel at about 20 feet.

In a feeble moraine on the north side of Little Elkhart River, in the western part of the county, the wells are usually about 30 feet in depth; after penetrating 10 to 20 feet of till they enter sand. South of Little Elkhart River the wells are mainly through till. The average depth is 30 or 40 feet, but occasional wells reach 60 feet.

In the gravel plain along Little Elkhart River the wells are usually but 12 to 20 feet in depth, entirely through gravel and sand.

At Lagrange wells are obtained at about 100 feet at the city waterworks, but private wells seldom exceed 40 feet. The detailed record

[1] See Eighteenth Ann. Rept. Indiana Geol. Survey, p. 81.

of four of the waterworks wells, published by Dr. Dryer,[1] show alternations of sand and gravel with till, in which the thickest beds are but 20 to 25 feet. In well No. 1, 92 feet in depth, the gravel beds amount to 32 feet, the thickest bed being 12 feet in the upper part of the section. In well No. 2, 102 feet in depth, the gravel and sand amount to 47 feet, of which 17 feet occur at the bottom of the well. In well No. 3, 98 feet in depth, the sand and gravel amount to 34 feet. In well No. 4, 111 feet in depth, the sand and gravel amount to 33 feet. These wells are within the area of an ordinary town lot, and yet Dr. Dryer reports that the majority of strata can not be correlated in any two of them. In well No. 1 there are 6 beds of gravel; in wells Nos. 2–4, but 5 beds of sand and gravel.

A well near the jail at Lagrange penetrates—

	Feet.
1. Yellow till	8
2. Dry sand	30
3. Gravel with water	2
Total	40

A prospect boring for artesian water at the jail penetrated—

	Feet.
1. Yellow till	15
2. Blue till, with thin beds of sand	50
3. A brown mold or soil	4
4. Cemented gravel	5
5. Loose gravel with water	8
6. Blue till	45
7. Cemented gravel	8
8. Dry sand and gravel	70
Total	205

The boring was abandoned without obtaining a flow or reaching rock strata.

A well on a sharp morainic ridge about 4 miles east of Lagrange, 202 feet in depth, failed to find water. Another well on the same farm obtained water at 175 feet. Both wells were mainly through till. A neighboring well, only 62 feet in depth, obtained water in gravel below till at about 60 feet.

A well for Dr. Drake, one-half mile north of Valentine, has the following section:

	Feet.
1. Sandy yellow till	10
2. Blue till	41
3. Gravel with inflammable gas	3
4. Blue clay	46
5. Black muck with leaves and inflammable gas	6
6. Soft blue clay	24
7. Water-bearing sand, coarse at bottom	10
Total	140

[1] Eighteenth Ann. Rept. Indiana Geol. Survey, pp. 80-81.

A well in the southeast part of the county, one-half mile east of South Milford, penetrates—

	Feet.
1. Sandy yellow till	20
2. Blue till	49
3. Very fine sand	20
Total	89

A similar fine sand was found in the well at Joseph Ryer's, 4 miles north of Wolcottville, at 30 to 108 feet from the surface.

A well in the west part of Milford Township, 3 miles north of county line, 97 feet in depth, is largely through sand, gravel, and cobble.

In the vicinity of Pretty Lake and Long Lake, in Milford Township, in the southeast part of the county, there are gravel plains on which wells obtained water at 30 or 40 feet without reaching the bottom of the gravel. On bordering districts wells usually penetrate 25 to 40 feet of till before reaching a water-bearing gravel.

Dr. Dryer reports the occurrence of coal in the drift beds in the southwest part of the county at depths of 76 feet in two neighboring wells under which beds of water-bearing gravel occur. A boring on a neighboring farm is thought to strike shale at 150 feet.

STEUBEN COUNTY.

General statement.—Steuben County is situated in the extreme northeast corner of the State, having Michigan on its northern and Ohio on its eastern boundary. On its western border is Lagrange and on its southern border Dekalb County. Its area is about 330 square miles. The entire county, except a valley in its southeast corner, stands above the 900-foot contour, and a portion of it rises above 1,100 feet, with occasional points 1,150 feet or more. It is estimated that at least one-half of the county stands above the 1,000-foot contour. The great elevation of this county is not due to an elevated rock surface, but to the heavy accumulations of drift. Its western half is occupied by the great interlobate moraine formed between the Erie lobe and the Saginaw lobe.

The topography of the western half of the county is of the knob-and-basin type, and several lakes are inclosed among the morainic knolls and ridges. These lakes have the advantage of beautiful scenery, pure water, and an excellent stock of fish. They are justly the pride of the inhabitants of the county. The largest lake, James Lake, has a length of 5 miles and an average width of half a mile. It is situated near the north line of the county and surrounded by sharp morainic knolls, which rise in places to a height of more than 100 feet above its surface. About this lake is a group of smaller ones, among which Jimerson, Crooked, Loon, Center, and Gage lakes are worthy of mention. These lakes are all tributary to Fawn River and discharge northwestward. South of them is a chain of lakes,

which are traversed by Pigeon River. Pleasant Lake, the most conspicuous of these lakes, is about 1 mile in length and one-fourth mile in average width. Below this lake the stream passes through Golden Lake and Hogback Lake, the latter receiving its name from a precipitous ridge of bowlders and gravel which stands on its shore. In the extreme southwestern part of the county is another chain of lakes drained by Turkey Creek, a south tributary of Pigeon River. The largest of these, Big Turkey, has a length of about 2½ miles and a maximum width of one-half mile.

A moraine of the Lake Erie lobe traverses the eastern part of the county in a north to south direction. This has gentler contours than the interlobate moraine, but incloses several lakelets among its knolls and ridges. The most conspicuous are Clear Lake, in the northeast corner of the county, having an area of about 2 square miles, and Fish Lake, in the southeast corner, having an area of a little more than 1 square mile. These lakes are tributary to the St. Joseph-of-the-Maumee River. A detailed discussion of the several lakes just mentioned, with observations on the size, depth, and character of their bottoms, is presented by Dr. Dryer in his report on Steuben County.[1] To this report the writer is indebted for the data concerning the dimensions of the lakes. It is suggested by Dr. Dryer that the city of Fort Wayne could find no better source of water supply than these lakes in the southern part of Steuben County.

The only level land in the county of notable extent is found in a narrow plain lying between the interlobate moraine and the Erie moraine just mentioned. It has a breadth of 2 to 5 miles and extends the entire length of the county.

The valleys of Fawn River, Pigeon River, Turkey Creek, and Fish Creek traverse gravelly districts, in which wells may be obtained at comparatively slight depth. The interlobate moraine varies greatly in the constitution of its drift and in the depth at which water may be obtained. Wells are not, however, as a rule, difficult to obtain, their average depth being not more than 30 or 40 feet. On the Erie moraine, in the eastern part of the county, and also on the plain west of it, the drift is largely a compact till, and the wells are not infrequently put down to a depth of 100 feet or more.

So far as known no wells in the county have reached rock, but the greatest ascertained depths are not more than 160 to 175 feet.

Individual wells.—Wells in the vicinity of Angola present much variety in material penetrated. Immediately north of the city is a small district where they obtain water at depths of 20 or 30 feet. Some wells in the city also obtain water at slight depth after penetrating a few feet of till. Several wells are put down to depths of 80 to 100 feet

[1] Seventeenth Ann. Rept. Indiana Geol. Survey, 1891, pp. 120-134.

or more. A well at the Tri-State Normal College has the following section:

	Feet.
1. Yellow till	20
2. Blue till	3
3. Reddish gravelly clay, with thin beds of sand	75
4. Gravel with water	6
Total	104

A well on the moraine west of Angola, near Fox Lake, 130 feet deep, was mainly in till. A well 3 miles north of Angola, of the same depth, was mainly in sand and gravel. On a gravel plain on south side of Turkey Lake two wells have a depth of 114 feet, largely through till after penetrating a few feet of surface gravel. A well on an elevated part of the moraine west of Turkey Lake in section 33, Salem Township, 90 feet in depth, was mainly in till. A well 2 miles southeast of Salem Center, 160 feet in depth, penetrates yellow or gray till 40 feet, below which it was mainly in blue till.

Near Hudson wells 80 feet in depth penetrate about 30 feet of sand and gravel and then enter blue till. A well 3 miles west of Hudson, 100 feet in depth, was mainly till.

Wells near Metz, in the eastern part of the county, are frequently 100 feet in depth, mainly till. One well 2 miles southwest of Metz, 103 feet in depth, is in till to within 2 to 3 feet of bottom.

Wells in the vicinity of Fish Lake, in the southeastern part of the county, obtain water in gravel at 15 to 25 feet. But within 2 miles back from the lake are frequently through till to a depth of 100 feet and occasionally 150 feet.

DEKALB COUNTY.

General statement.—Dekalb County is situated on the eastern boundary of the State, immediately south of Steuben. It has an area of 370 square miles. Its northwestern corner is occupied by the interlobate moraine of the Erie and Saginaw lobes. The higher part of the moraine rises above the 1,000-foot contour, but its eastern border stands only about 900 feet. The greater part of the county is occupied by a till plain, standing about 850 to 900 feet above tide. In the southeastern part, on the borders of the St. Joseph-of-the-Maumee, are two moraines of the Erie lobe, but they rise scarcely 25 feet above the border plains.

Over the greater part of the county there is a sheet of till extending to an average depth of about 50 feet from the surface, in which water is seldom obtained in large amount. Below this sheet of till the drift appears to be very largely sand and gravel and yields an unlimited amount of water. There are narrow belts or small areas, usually bordering the valleys, in which water may be obtained in gravel or sand at comparatively slight depth.

The thickness of the drift in this county has been determined at four villages, as follows: Butler, 378 feet; Waterloo, 365 feet; Auburn, 280 feet; Garrett, 318 feet. A boring in the extreme southeastern part of the county, near Spencerville, was carried to a depth of 198 feet without reaching rock. A boring at Kendallville, just west of this county, penetrated 485 feet of drift. These borings, together with the four which strike rock within the county, have sufficiently wide distribution to justify the interpretation that the drift of the county probably averages over 300 feet in thickness, and may possibly average 400 feet. The four borings which enter the rock are on a till plain which stands more than 100 feet below the elevated northwestern portion of the county. The rock floor in but one instance (at Auburn) stands above the level of Lake Erie.

Individual wells.—The gas boring at Butler is reported by Dr. Dryer to have the following section:

	Feet.
1. Hardpan (till)	15
2. Gravel and coarse sand	275
3. Red quicksand	40
4. Compact clay	45
5. Cobblestones and bowlders	3
6. Black shale	108
7. Limestone	1,064
8. Shale	500
9. Trenton limestone penetrated	89
Total	2,139

Water in large amount is found in the glacial drift. Salt water was struck in the Trenton.

The water wells in the vicinity of Butler usually obtain their supply from depths of 20 to 35 feet, though they are occasionally put down to a depth of 150 feet. In the northern part of the county, 6 or 8 miles northwest from Butler, wells are through till to a depth of 60 or 80 feet before striking water-bearing gravel or sand. The record of a well 3 miles south of Hudson was also obtained, which penetrated 75 to 80 feet of till.

At Waterloo the drift at the gas well is as follows:

	Feet.
1. Till	40
2. Sand and gravel with water	270
3. Blue clay without pebbles	45
4. Gravel and cobble	10
Total	365

At Auburn two gas wells each penetrate about 280 feet of drift, which is largely till in its upper half and largely sand and gravel in lower half.

There are occasional shallow flowing wells in the vicinity of Auburn on low ground on the border of Cedar Creek, water being obtained from the gravel below the till. The head is seldom more than 2 to 5 feet below the surface in that locality.

The gas boring at Garrett penetrates about 50 feet of till, beneath which is 200 feet or more of sand, with a thin bed of gravel at the bottom of the drift. This sand and gravel afford a large amount of water. In Garrett water is often obtained at 40 feet, but the wells are in some cases 75 to 100 feet. North and west from Garrett there are extensive marshes with sandy borders, where wells are obtained at slight depth without entering the till.

Along Cedar Creek Valley, in the southern part of Dekalb County, water is usually obtained at 30 or 40 feet. The wells penetrate more gravel than till, though both are present.

A well in the southeastern part of the county, near the village of St. Joseph, and but a few rods from the bank of the river, 110 feet in depth, is mainly through sand and gravel.

A well on the farm of Christian Hirsh, east of St. Joseph River, near Spencerville, has the following section:

	Feet.
1. Yellow till	10
2. Blue till	59
3. Fine sand	120
4. Gravel	9
Total	198

In that neighborhood there are perhaps a dozen other wells 60 to 100 feet in depth, mainly through till.

NOBLE COUNTY.

General statement.—Noble County is situated immediately east of Dekalb and has an area of 420 square miles. The entire county has a morainic topography, the greater part of it being the interlobate moraine of the Erie and Saginaw lobes. In the northwestern part of the county the Saginaw moraines branch off from the interlobate belt, while in the southeastern part an Erie moraine is parallel to and closely associated with the interlobate belt.

The portion of the county occupied by the interlobate moraine includes many lakes, some of which have an area of 1 to 2 miles or more each. The most important ones are Crooked, Tippecanoe, and Loon lakes, in the southern part of the country, which constitute the head waters of Tippecanoe River. There are several in the northern part of the county and in the adjacent portion of Lagrange County, constituting the head waters of Elkhart River. A few in the western part of the county are also tributary to Elkhart River. These lakes are usually bordered by extensive marshes, though in a few cases morainic knolls and ridges rise from their immediate borders. Those in the southern part of the county tributary to Tippecanoe River have less marshy borders than the lakes tributary to the Elkhart, and the morainic hills in that portion of the county also rise more prominently above the lake basins than in the northern or western portion of the county. While the beauty of scenery does not equal

that around the lakes of Steuben County, the quality of the water is excellent and the lakes are well stocked with fish.

Except in the southeastern portion of the county wells are usually obtained at moderate depths, seldom exceeding 50 feet. The interlobate moraine and the Saginaw moraines connected with it contain usually a large amount of sand and gravel with the till. The Erie moraine, on the southeast border of the county, has much less sand and gravel associated with it, and in consequence many wells need to be sunk to a depth of 100 feet or more.

The thickness of the drift is known at three points, Ligonier, Kendallville, and Albion. At Kendallville it is 485 feet and at Albion 375 feet, but at Ligonier it is only 169 feet. It seems probable that the average thickness of the drift for the county may equal that at Albion.

Individual wells.—The following detailed record of the drift penetrated at Albion was kept by Prof. W. B. Van Gorder, of that city:

	Feet.
1. Yellow clay	10
2. Blue clay	10
3. Sand and gravel	115
4. Blue clay	20
5. Sand and gravel, with streaks of blue clay	52
6. Sand and gravel	81
7. Blue clay, with thin beds of sand	52
8. Gravel	5
9. Red bowlder clay	15
10. Sand	5
11. Slate (?)	1
12. Sand	9
Total	375

The water wells at Albion are usually obtained at 60 to 100 feet in the sand and gravel below the upper sheet of till. They penetrate from 15 to 30 feet of till at the surface. The underlying sand is either too fine or contains too little water in its upper portion to supply the wells.

The drift at the Kendallville gas-well boring (485 feet), specimens of which were preserved in a glass tube, appears to be mainly sand and gravel below a depth of 20 feet. A record of a water well in this village near the gas well was furnished by the driller, J. Hart, and is as follows:

	Feet.
1. Yellow till	10
2. Dry sand	15
3. Sand, with some gravel, but little water	50
4. Soft blue till	29
5. Gravel, with large amount of water	4
Total	108

A still deeper well at Dr. Mayer's residence in Kendallville is reported by the driller, Mr. Diebolt, to have the following section:

	Feet.
1. Surface clay	5
2. Dry gravel	20
3. Water gravel	10
4. Soft blue clay	25
5. Water gravel	20
6. Hard blue till	70
7. Soft blue till	25
8. Water gravel	10
Total	185

A well at Mr. Henry Mayer's in the east part of Kendallville, 60 feet in depth, penetrates—

	Feet.
1. Yellow till	28
2. Blue quicksand	26
3. Ferruginous crust	1
4. Water gravel	5
Total	60

From these sections it appears that the drift may have considerable variability within the limits of the village.

A well about 3 miles east of Kendallville, in section 1, Allen Township, penetrates—

	Feet.
1. Yellow till	14
2. Blue-gray till, with thin beds of sand or gravel	192
Total	206

This well is in the Erie drift above referred to.

A well 4 miles northeast of Kendallville is reported to penetrate 120 feet of till, and one in the extreme northeast corner of the county 75 feet, before obtaining water.

It is reported by Mr. Diebolt that the blue till of the Erie drift found south from Kendallville is much harder to penetrate than the blue till of the Saginaw drift found north and west of that village. A well 1 mile south from Kendallville penetrates—

	Feet.
1. Yellow till	20
2. Hard blue till	40
3. Cemented gravel	15
4. Water gravel	10
Total	85

A well in section 17, Allen Township, on a prominent drift knoll, is 177 feet deep, mainly in till.

Wells in the vicinity of Avilla, and for 5 or 6 miles west from that village, are frequently put down to a depth of 90 or 100 feet, mainly through till. Several wells in the southeastern part of the county,

in Swan and Greene townships, are reported to be mainly through till to a depth of 75 to 160 feet. Dug wells, however, are often obtained in that region at a depth of 20 to 40 feet from thin beds of sand or gravel included in the till.

In the district southeast and south from Albion records of several deep wells were obtained. One near Noblesville, 161 feet in depth, was entirely in till. Another in section 11, Greene Township, was in till to a depth of 100 feet before striking water-bearing gravel. A well in section 35, Jefferson Township, enters gravel below till at 63 feet. One in section 26, Jefferson Township, penetrates till, with thin beds of sand or gravel, to a depth of 102 feet. One in section 16, Jefferson Township, enters water-bearing gravel at 70 feet.

Northeast from Albion, in the vicinity of Rome City, one well, 117 feet in depth, penetrates—

	Feet.
1. Sand	53
2. Soft, adhesive blue clay	40
3. Sand and gravel	24
Total	117

Another, 122 feet in depth, penetrates—

	Feet.
1. Yellow till	20
2. Soft blue till	45
3. Quicksand	8
4. Soft blue till	44
5. Gravel with water	5
Total	122

A well in section 23, Wayne Township, 147 feet in depth, penetrates till, with thin beds of sand and gravel, its entire depth. Another well in the northern part of the same section has a depth of 164 feet in similar material. A well in section 27, 117 feet in depth, also has a similar section.

In the vicinity of Brimfield the surface is sandy to a depth of a few feet, but wells penetrate a large amount of till. One well, a mile east of Brimfield, 60 feet in depth, is mainly in blue till.

A well near Skinner Lake, 3 miles east of Albion, penetrates—

	Feet.
1. Yellow till	12
2. Soft blue till	52
3. Sand, with water	4
Total	68

In the northwest part of Noble County, near Hawville, wells show a variable structure, some being entirely in sand and gravel to a depth of 30 or 40 feet, while others are in till to even greater depths before striking a water-bearing gravel.

Wells in the southwestern part of the county usually have 40 to 75 feet, more generally 75 feet, of till at surface before entering beds affording a strong supply of water.

From Albion west and northwest the drift appears to be largely of a gravelly constitution and wells are obtained without penetrating to great depth. At Ligonier the depth is about 35 feet. The wells at that village usually penetrate 10 to 20 feet of till before entering the water-bearing gravel. This gravel is shown by the gas-well boring to be 125 feet in depth. There was a large supply of fresh water at about 200 feet in the gas boring, 30 feet below the rock surface.

KOSCIUSKO COUNTY.

General statement.—Kosciusko County is situated in the middle portion of the second tier of counties from the north boundary of the State, being immediately south of Elkhart County and west of Noble County. It has an area of 556 square miles, being exceeded in area by only two other counties in the State.

The eastern and southern portions of the county are situated on the interlobate moraine of the Saginaw and Erie lobe, except the extreme southeastern portion, which is occupied by a moraine of the Erie lobe (the Mississinewa). The northwestern portion of the county, comprising about one-fourth its area, is occupied largely by gravel plains and by marshes. It is much lower than the moraine, and yet the divide between the Wabash and the Lake Michigan drainage systems passes through it. The general elevation of the plain is about 800 feet above tide. The moraine stands 900 feet or more in its higher portion.

Along the interlobate moraine in the eastern portion of the county there are numerous lakes, one of which, Turkey Lake, has the distinction of being the largest lake in Indiana. The area is probably about 8 square miles, its length being fully 6 miles and its width a mile or more. There are probably a half dozen other lakes having areas of 1 to 2 square miles each, among which may be mentioned Wawasee, Tippecanoe, Boydstown, Barbers, Big Eagle, Little Eagle, and Pike lakes. These lakes are bordered on one or more sides by morainic knolls and ridges, but have usually extensive marshes on other sides. Turkey Lake lies on the inner border of a Saginaw moraine that leaves the interlobate moraine near the border of Noble and Kosciusko counties and passes northwestward into Elkhart County. Wawasee, Tippecanoe, and Boydstown lakes are situated on the outer border of the same moraine. These lakes have a pure supply of water and are said to be well stocked with fish. A biological survey of Turkey Lake is in progress under the auspices of the State University. A few small lakes occur along the interlobate moraine in the southern part of the county, among which may be mentioned Yellow Creek, Beaver Dam, Silver, and Rock lakes. None of these have an area of 1 square mile. They lie in the midst of morainic knolls and ridges, with but little marshy land on their borders.

This county is as well favored, perhaps, as any in the State in abundant supplies of water for wells at shallow depth. On the plain in the northwestern portion the wells rarely exceed 40 feet and are

usually but 10 to 20 feet in depth. Along the moraine, even in its most elevated portion, it is rare to find wells that exceed 40 feet in depth. The drift appears to consist more largely of sand and gravel than of till, unless it be in the extreme southeastern portion of the county occupied by the Erie moraine.

The thickness of the drift is known only in the vicinity of Warsaw, the county seat, where gas-well borings show it to be in one case 247 and in another 255 feet. A well 3 miles west of Warsaw penetrates 243 feet of drift.

Individual wells.—At Milford, on a gravel plain in the northern part of the county, the wells have a depth of about 20 feet, entirely through gravel and sand. In the vicinity of North Galveston, also on the gravel plain, wells enter till below the gravel at about 25 feet. In the vicinity of Oswego, also, the bottom of the sand and gravel is reached at 25 feet or less. Water is usually obtained at both these villages and in the intervening country near the base of the gravel. West from North Galveston the plain has a till deposit at the surface, being outside the limits of the gravel overwash. But wells usually find the water-bearing sand and gravel at 15 or 20 feet.

On Bone Prairie the wells are in some cases put down to a depth of 60 feet, largely through till, there being only a slight coating of surface gravel.

At Atwood wells range in depth from 8 feet to 40 feet, but usually obtain water below yellow till at about 20 feet.

At Etna Green wells penetrate 20 or 30 feet of till before entering water-bearing gravel.

In the eastern part of the county the wells along the Tippecanoe River and southward for a mile or two are only 10 or 12 feet in depth, largely in sand. North from the river they penetrate till to a depth of 30 to 50 feet.

On the border of Turkey Lake a well 40 feet deep is reported to have penetrated:

	Feet.
1. Gravel	12
2. Till	28
3. Water-bearing gravel at bottom.	

In the vicinity of Pierceton wells occasionally penetrate 60 feet or more of till. A tubular well 1 mile northeast of Pierceton penetrates till about 100 feet.

At Kosciusko there is a surface gravel several feet in depth, but wells usually pass through it and an underlying till into a deeper gravel at about 25 feet.

For 2 to 4 miles east from Warsaw the wells are largely through till and have a depth of 18 to 40 feet.

In the east part of Warsaw a flowing well has been obtained on low ground between Pike and Center lakes at a depth of 102 feet. Its head is about 4 feet above the surface. At one of the gas-well borings

in Warsaw there is also a flow of water discharging rapidly from a 7-inch pipe at a height of 2 feet above the surface. As it contains much sulphureted hydrogen, it is probable that a portion of the water is from the rock strata. The overflow is probably caused from accession of water from the drift. In both the gas-well borings at Warsaw the drift is largely sand, filled with water.

In the western portion of the county, south from the Tippecanoe River, in the vicinity of Claypool, Burkett, and Mentone, wells usually penetrate 25 to 40 feet or more of till and occasionally 60 feet.

MARSHALL COUNTY.

General statement.—Marshall County is situated west of Kosciusko County, in the middle portion of the second tier of counties from the north boundary of the State. It has an area of 440 square miles.

The prominent Maxinkuckee moraine leads through the western range of townships from south to north. It also swings southeastward near the southern boundary of the county and has its inner border within the limits of Marshall County as far east as the Tippecanoe River. This moraine constitutes the principal topographic feature of the county, the remainder of the county being a gently undulating plain, with occasional slight ridging of the drift.

Lake Maxinkuckee, from which the moraine takes its name, is situated in the southwestern township of the county and is surrounded by a series of morainic knolls and ridges, which add to the attractiveness of its scenery. The lake occupies perhaps 2 square miles, and its maximum depth is 76 feet. A large number of springs occur on its borders, and its water is remarkably clear and pure. The lake is said to abound in fish. On the borders of the lake several clubhouses have been built by Indianapolis, Peru, Plymouth, and other clubs, and summer cottages are numerous along its shore.

Along the border of the lake several flowing wells have been obtained, which rise to a height of 12 to 30 feet above the lake surface. The first well driven was only 13 feet in depth. Several have a depth of but 20 or 25 feet. Others are put down to a depth of 50 to 75 feet. One well has a depth of 160 feet, and one reached a depth of 203 feet. There appear to be several water horizons, but the head is no greater from the deep wells than from the shallow ones, and the upper horizon is as strong as any.

Two other prominent localities for obtaining flowing wells are found in this county, one being along Yellow River, in the vicinity of Plymouth, the other along Yellowbank Creek, in the vicinity of Teegarden. Those in the vicinity of Plymouth are usually but 40 or 50 feet. Those in the vicinity of Teegarden are 40 to 100 feet. In all cases the flowing wells are from beds of sand or gravel beneath a sheet of till.

The bottom of the drift has, so far as known to the writer, been

reached in but one locality, Plymouth, the county seat, where a gas boring entered rock at 242 feet.

Individual wells.—On the head waters of Yellow River, near Bremen, in the northeastern part of the county, wells are usually but 12 to 20 feet in depth and penetrate mainly sand and gravel.

At Bremen, however, there is a small ridge of till on which the average depth of wells is about 40 feet. One well in the west part of the village is 100 feet in depth, mainly blue till.

Wells at Inwood are mainly through sand and gravel, though penetrating thin beds of clay; the depth ranges from 20 to 50 feet. Between Inwood and Plymouth the usual depth is about 35 feet, water being obtained in sand or gravel below till.

The gas well at Plymouth has the following section of drift:

	Feet.
1. Sand and gravel	40
2. Till	50
3. Mainly sand and gravel	150
Total	240

Flowing wells in the vicinity of Plymouth are obtained in a narrow belt, scarcely 40 rods in width, along the Yellow River bottoms. They usually penetrate several feet of sand at the surface, below which are alternations of till with sand beds. The best flow is obtained at a depth of 42 to 45 feet.

The flowing wells along Yellowbank Creek are found for 2 or 3 miles west from Teegarden. They penetrate much blue till before reaching a water vein. The water horizon appears to vary greatly in depth in the several wells, there being a range from 40 feet to about 100 feet.

In the southern part of the county, on the plain east and north from the Maxinkuckee moraine, water is usually obtained at 10 to 20 feet. At Tippecanoe Station, on the borders of Tippecanoe River, the depth is but 10 or 15 feet. In the north part of Walnut Township, where the surface is sandy and poorly drained, wells seldom exceed 10 feet in depth. In portions of Walnut Township, although surface bowlders abound as in till tracts, yet the underlying deposits are mainly sand, and wells are found at depths of 10 to 20 feet.

The deepest of the flowing wells at Lake Maxinkuckee is at the residence of D. W. Morman. At the time of the writer's visit the water scarcely reached the surface, 20 feet above the level of the lake. Of the 203 feet penetrated, fully 90 per cent is thought to have been till, the sand beds being but a few feet in thickness.

Messrs. Thompson and Lee, in their report on Marshall County,[1] note two wells on the northeast shore which have a head 31 feet above

[1] Fifteenth Ann. Rept. Indiana Geol. Survey, pp. 182-186.

the surface of the lake. The wells are each 72 feet in depth and have the following section:

	Feet.
1. Soil and yellow clay	8
2. Sand	14
3. Blue clay	38
4. Sand and gravel	12
Total	72

A short distance east from these wells the head in a well 50 feet in depth is but 19 feet above the lake. The well at the Peru Clubhouse, on the east side of the lake, was bored to a depth of 160 feet and obtained only a weak flow. At the Indianapolis Clubhouse a good flow was obtained at only 27 feet. At the Highland House a well 33 feet in depth entered water-bearing sand at a depth of 13 feet. Near the Highland House D. W. Morman, of Indianapolis, has several wells. Four of them, averaging about 22 feet in depth, are estimated to have a combined discharge of 15 barrels per minute. These wells feed a ram which supply the grounds with water. Mr. Morman also has a deeper well, with the following section, in which the flow is obtained from the sand above the blue clay:

	Feet.
1. Yellow clay	11
2. Sand	25
3. Blue clay	62
Total	98

STARKE COUNTY.

General statement.—Starke County is situated on the eastern border of the head of the Kankakee marsh, in the northwestern part of the State. Its area is about 300 square miles. It is a much lower district than Marshall County on the east, and the surface is covered by sand dunes or marshes, except in the southeast portion, where a small till plain occurs which is nearly free from sand. Underneath the sand, throughout the inhabited portion of the county, a blue till is often found at depths of 10 to 40 feet, but wells are usually obtained in the sand above the till.

A boring at North Judson, for the purpose of obtaining natural gas, shows the drift to have a thickness of 198 feet. A gas boring at Knox also penetrated a large amount of drift, but the precise depth at which rock is struck has not been ascertained. In both borings till is entered below the sand at a slight depth and constitutes the main part of the drift.

Individual wells.—At Knox, the county seat, wells are obtained at various depths, ranging from 14 up to 40 feet, the deeper ones being on sand ridges and the shallow ones on low ground among the ridges. At the gas-well boring at Knox the water rose nearly to the level of

the surface, but the pipes have been withdrawn and the well abandoned. Some of the shallower wells are very liable to contamination.

At North Judson the water is obtained near the base of the sand at depths of 16 to 30 feet, the deeper wells being on sand ridges. There appears to be a liability to contamination of water in this village.

A boring at the north end of Cedar Lake, in the southeastern part of the county, is reported to have the following section:

	Feet.
1. Sand	5
2. Blue clay	9½
3. Sand and gravel	3
4. Blue clay	18
Total	35½

Cedar Lake is said to have a depth of 34 feet, with bowlder clay at bottom.[1]

Near the east border of the county several wells have been put down to depths of 30 to 100 feet, mainly through till. The deepest one (at Mr. Pette's, in sec. 24, T. 32, R. 1 W.), about 100 feet in depth, has the following section:

	Feet.
1. Yellow till	10 to 12
2. Blue till	16
3. Gray sand	52
4. Blue clay	4
5. Cemented sand and gravel	15
Total	97 to 99

A mile north from Mr. Pette's, at David Fetter's, a well penetrates—

	Feet.
1. Sandy till	5
2. Blue till	12
3. Quicksand	5
4. Blue till	30
Total	52

NEWTON COUNTY.

General statement.—Newton County is situated on the west border of the State, immediately south of Kankakee River. It has an area of about 400 square miles. The northern third of the county falls within the limits of the Kankakee marsh and the sandy ridges which form the southern border. The central portion of the county is occupied by a moraine 3 to 5 miles in width, which leads across it from west to east. This moraine rises from 50 to 75 feet above the bordering plains on either side and has a gently undulating surface. South from the moraine is a plain traversed by the Iroquois River, which extends southward beyond the limits of the county.

In the sandy northern portion of the county wells were, in the early days of settlement, put down to a slight depth and obtained their water in the sand; but within the past few years they have been

[1] Fifteenth Ann. Rept. Indiana Geol. Survey, p. 224.

sunk to depths of 50 to 100 feet or more, through a sheet of blue till which underlies the sand, to beds of sand and gravel which furnish a better quality of water than that in the surface sand. Along the morainic ridge wells are usually obtained in the glacial drift, but have occasionally been put down in the underlying rock. The distance to rock is 100 to 150 feet or more. The best wells on the moraine are deep ones, extending nearly to the base of the drift. The moraine appears to be composed of a nearly solid bed of till. In the plain south of the moraine many wells are sunk 75 to 100 feet or more to obtain a better supply of water than is afforded at shallower depths. On the immediate borders of the Iroquois River wells reach a depth of 100 feet without entering rock, but in the southern portion of the county rock is often entered at 25 feet or less. The rock surface appears to be generally much higher on the southern borders of the county than in the district north from the Iroquois River.

Individual wells.—Records of several deep wells in this county are presented in the Twelfth Annual Report of the State Geologist, and are also given below:

Twelve wells, bored by Hyer Brothers, in and near Kentland, penetrated, on an average, the beds named below:

	Feet.
1. Soil	2
3. Yellow clay	10
3. Blue glacial clay	45
4. Sharp sand	2
Total	59

Water rises to within 18 or 20 feet of the surface.

The well at the public square in Kentland obtained a flow of water at 300 feet and penetrated the following strata:

	Feet.
1. Glacial deposits	150
2. Black slate	73
3. Devonian limestone	25
4. Upper Silurian limestone	120
Total	368

At Kent's warehouse, in Kentland, an unsuccessful boring for water penetrated:

	Feet.
1. Glacial deposits	82
2. Black slate	80
Total	162

A well at Alexander Kent's, 1 mile northeast of Kentland, 320 feet in depth, penetrated 182 feet of drift. A well on his farm, 4 miles northeast of Kentland, found only 50 feet of glacial drift and obtained water in limestone at 53 feet. A well on another farm, 2 miles southwest of Kentland, struck limestone at 50 feet and there obtained water.

At Mr. Brush's, 3 miles southwest of Kentland, a flowing well has the following section:

	Feet.
1. Soil and yellow clay	9
2. Sand and gravel	4
3. Blue clay	68
4. Hardpan gravel	4
5. Limestone	1
Total	86

Another flowing well was obtained at Mr. Drake's, sec. 25, T. 27, R. 9 W., 3 miles east of Kentland. After penetrating 33 feet of till it enters a bed of sand and gravel, from which the flow is obtained.

Several flowing wells have been obtained in the Iroquois Valley on the overflow plain of the river. An average section of several of these wells, furnished by David McKenzie, their driller, is as follows:

	Feet.
1. Soil and sand	14 to 17
2. Blue clay	30
3. Hardpan gravel	5
4. Blue sand with flow of water	4
Total	53 to 56

A well near the State line west of Kentland, reported by Mr. McKenzie, penetrates—

	Feet.
1. Soil	3
2. Yellow clay	6
3. Blue glacial clay	25
4. Blue glacial clay with partings of sand	46
5. Gravel and fine sand	3
Total	83

A well on Mr. Peterson's farm, near the State line, in sec. 11, T. 28, R. 10 W., on a high part of the moraine, referred to above, penetrates 168 feet of drift without reaching the rock. Mr. McKenzie reports the following section:

	Feet.
1. Soil and yellow clay	6
2. Blue bowlder clay	154
3. Fine gravel and sand with water	8
Total	168

An almost identical series was found at Mr. Besicker's, in the adjoining section on the south, where a well 171 feet in depth was in till to a depth of 165 feet before striking water-bearing strata.

About 5 miles northwest from Kentland, in sec. 13, T. 27, R. 10 W., four wells on the farm of Mr. J. V. Speck are reported to have passed through a brown swamp muck at the bottom of the till, about 80 feet below the surface, beneath which there was water-bearing sand and gravel.

At Morocco a boring at the Creamery penetrated 127 feet of till, at which depth limestone was entered.

Several wells near the range line east of Morocco, on the north slope of the moraine, enter rock at 110 to 120 feet, after penetrating a solid bed of till.

At Mount Ayer, also on the moraine, near the eastern border of the county, many wells get a good supply of water in gravel at 30 or 35 feet, but a few have been put down to depths of 140 to 160 feet. Mr. Ashby's well penetrated 120 feet of drift and 20 feet of rock, as follows:

	Feet.
1. Yellow till	10
2. Blue sand	20
3. Blue till	90
4. Blue shale	20
5. Hard flint rock at bottom.	
Total	140

Mr. Lewis Marion's well in the southwest part of the village strikes shale at 139 feet. W. J. Young's well strikes shale at about 150 feet, and a hard rock at 162 feet. The drift is mainly till.

In the vicinity of Brooke a soft till is penetrated to a depth of 50 or 60 feet, below which there is a harder till, extending either to the rock or to water-bearing beds. Several wells between Brooke and the east line of the county overflow when on the low bottoms of the Iroquois River, and rise nearly to the surface on the plain that borders the river. Their depth ranges from 80 feet up to 120 feet or more. Rock is usually struck at 100 to 120 feet. The following section at J. B. Lyon's, 1 mile north of Brooke, will illustrate the structure:

	Feet.
1. Yellow till	10
2. Blue sand, very fine	5
3. Soft blue till	55
4. Blue-brown till	36
Total	106

Rock was struck at 106 feet. Water stands 12 feet below the surface.

In the southwest part of T. 27, R. 8 W., and southeast part of T. 27, R. 9 W., near the south line of the county, several wells strike rock at 40 or 50 feet or less, and there are occasional outcrops of the Lockport (often called Niagara) limestone in low knolls rising a few feet above the level of the bordering plain. Eastward from there to Goodland the drift appears to be generally thin. Rock is struck at about 20 feet. The wells which obtain their water from the Lockport limestone, in the southern part of the county, often reach a depth of 250 to 300 feet, and obtain a water charged with sulphureted hydrogen.

A natural gas boring at Kentland, 1,325 feet in depth, obtained a sulphurous water with head 45 feet below the surface. It supplies the waterworks.

JASPER COUNTY.

General statement.—Jasper County is situated in the northwestern part of the State, immediately east of Newton County and south of the Kankakee marsh. Its area is 570 square miles, the second county in area in the State. Like Newton County, its northern third is covered by the Kankakee marsh and by sand ridges that form the south border of the marsh. Its central portion is traversed by a continuation of the moraine that passes eastward across Newton County. Its southern portion is a plain covered quite extensively with sand, which in places is drifted into dunes.

In the northern part of the county the drift deposits are 75 to 200 feet in depth, but in the central and southern portions, although the altitude is as great as in the northern portion, the drift deposits are generally quite thin, there being often only a coating of sand 10 to 20 feet in depth. In some wells in the northern part of the county (cited below) a hard till is found below the soft Wisconsin till which is probably Illinoian drift.

Individual wells.—On the borders of the Kankakee marsh, in the northern part of the county, wells are usually obtained at slight depth in the sand deposits. But upon approaching the moraine in the central portion of the county the sand has insufficient depth to afford good water, and wells are accordingly sunk to beds of sand and gravel beneath the till.

Two wells at Surrey enter rock at about 90 feet. They are mainly through till. Several borings for gas 2 or 3 miles north of Surrey, on the edge of the sandy ridges, strike rock at 80 or 90 feet. The drift is mainly till.

On the crest of the moraine southeast of Surrey a well at Charles Coen's, sec. 12, T. 29, R. 7 W., strikes rock at 192 feet, and there obtains water. A well at William Nowel's, in the same section, strikes rock at 140 feet and obtains water at 162 feet. In both wells the drift is mainly till.

In sec. 30, T. 30, R. 6 W., on the north border of the moraine, a well at Jacob Ush's obtains water at 146 feet without striking rock. Another at George Marcum's obtains water at 130 feet. In both wells a soft till is penetrated for about 90 feet, below which is a hard till, extending to the water-bearing sand and gravel. At J. S. Williams's, a short distance north from the wells just mentioned, a well was obtained at the bottom of the soft till at a depth of 97 feet.

A well in a low, marshy tract in sec. 15, T. 30, R. 6 W., enters rock at about 75 feet.

A well on the moraine in sec. 13, T. 30, R. 5 W., penetrates 102 feet of drift, mainly blue till. Another well in the same section penetrates 80 feet. A well at Mr. Osborne's, in section 1 of the same township, has 126 feet of drift, and one at Mr. Rayburn's, in section

2, 118 feet. In all these wells the water is obtained at slight depth in the underlying rock.

On the plain north of the moraine, in sec. 27, T. 31, R. 5 W., a well at James Gill's enters rock at 47 feet, after penetrating considerable till.

Passing southward near the east side of the county to the south border of the moraine, the rock is found to rise within a few feet of the surface. Wells in sec. 3, T. 29, R. 5 W., penetrate but 5 to 15 feet of drift. This region of thin drift extends southward beyond the limits of the county and westward to Rensselaer. Some of the wells obtain their water without entering the rock, but a large number are carried a few feet into the rock.

Immediately west of Rensselaer the rock surface suddenly drops down 75 or 100 feet or more, so that wells are 80 to 150 feet in drift. For example, a well on the south border of the moraine, in sec. 29, T. 29, R. 7 W., enters rock at 143 feet. A well on the plain south of the Iroquois River, in sec. 3, T. 28, R. 7 W., enters rock at about 80 feet. The rock surface continues low for several miles south from the Iroquois River, in the western part of the county, and wells are often 50 to 75 feet in depth without entering the rock.

In the southern half of T. 27, R. 7 W., the rock surface rises to a greater altitude than in the vicinity of Rensselaer. Although the general elevation is about 50 feet higher than at Rensselaer and the portion of the county east from that city, the wells in this southern end of the county often enter rock at 10 to 20 feet.

At Remington the dug wells are usually 12 to 20 feet in depth, obtaining water near the base of the drift. The drilled wells are 75 to 125 feet in depth. Robert Parker's well, 125 feet in depth, has the following section:

	Feet.
1. Drift	18
2. Shale	95 to 100
3. Solid stone, probably limestone	8 to 10
Total	125

The water rises from this depth within 18 feet of the surface. It contains sulphureted hydrogen in small amount.

Wells for water in the vicinity of Rensselaer range in depth from 30 feet to 200 feet. They enter rock at 6 to 15 feet. On the low ground along the river several of them have head sufficient to overflow, but at the general level of the town the water rises only within 5 or 6 feet of the surface. A gas-well boring at Rensselaer was carried to a depth of 1,275 feet, but the boring is not utilized, although a sulphurous water rises to the surface. This water is probably from the Lockport limestone, as in the water wells of the vicinity.

PULASKI COUNTY.

General statement.—Pulaski County is situated in the northwestern part of the State, immediately east of Jasper and south of Stark County. Its area is 430 square miles. Like Stark County, Pulaski is almost entirely occupied by sand ridges and marshes, there being only small areas of cultivable land free from sand, found chiefly on the eastern and southern borders of the county. Although it occupies the divide between the Kankakee, a tributary of the Illinois, and the Tippecanoe, a tributary of the Wabash, there is no dividing ridge, and large tracts in the northwestern part of the county might be drained with equal readiness to either stream. No adequate drainage lines have been developed in the portion of the county west from the Tippecanoe River. The portion east from the river is much better drained.

Individual wells.—In the northwestern portion of the county large areas have never been settled. On the tracts which are cultivated wells are usually obtained at 20 to 40 feet or less without reaching the bottom of the sand. In the southwestern portion of the county the drift deposits are very thin, and wells usually enter rock at 10 to 20 feet. At Medaryville, however, a well at the tile factory penetrates 92 feet of drift and obtains its water supply from the rock at 115 to 120 feet.

In the eastern part of the county wells are usually obtained at shallow depths, either in the sand or in beds of sand and gravel associated with the till.

At Winamac, the county seat, the wells often reach a depth of 50 to 60 feet. They pass through 10 to 25 feet of sand, or a sandy clay loam, below which is a bed of blue till, extending to the water-bearing gravel. The drift at this point is 110 feet in thickness. The gas-well boring, 1,200 feet in depth, obtains a flow of water estimated at 45 gallons per minute. The horizon at which the water was found has not been ascertained.

FULTON COUNTY.

General statement.—Fulton County is situated near the middle of the third tier of counties from the north boundary of the State, immediately east of Pulaski and south of Marshall County. It has an area of 380 square miles.

The surface is very diversified. In the western portion there is a till plain on which occasional drift ridges and knolls occur, and also a few sand ridges. Along the northern boundary there is the Maxinkuckee moraine, and in the eastern and southeastern portions the western slope of a bulky moraine formed by the Erie lobe, which connects in northeastern Fulton County with the Maxinkuckee moraine to form the great Erie-Saginaw interlobate moraine, which, as above noted, leads northeastward into Michigan through the northeastern

part of Indiana. West from the junction of these two moraines there is much marsh land with sandy ridges, which is imperfectly drained by southern tributaries of Tippecanoe River.

The thickness of the drift is known at Rochester, in the central portion of the county, and at Kewanna, in the western portion. At Rochester an artesian well at the court-house has 155 feet of drift, while a gas-well boring, 60 rods northeast from the court-house, has 245 feet. The altitude of the two wells is very nearly the same, and in both there are alternations of till with sand and gravel. At Kewanna the drift is 167 feet in one well and 208 feet in another. It is largely assorted material, but contains beds of blue till.

Individual wells.—Very few records of the sections of wells were obtained in this county, largely because of their shallowness. The great majority of wells are obtained at depths of 20 or 25 feet; in many cases at 12 or 14 feet. In the extreme northeast corner of the county, however, there is an area of a township or more on the east side of the Tippecanoe River where a compact till makes it necessary to sink wells to a depth of 60 or 80 feet. In one section six wells have an average depth of 70 feet. Another place in which wells are sometimes difficult to obtain is found in the northwest township of the county, in the Maxinkuckee moraine, but here it is rare for a well to exceed 60 feet in depth.

WHITLEY COUNTY.

General statement.—Whitley County is situated in the northeastern part of the State, immediately west of Allen and south of Noble County. It has an area of 330 square miles.

The extreme northwestern border of the county is occupied by the interlobate Erie-Saginaw moraine. The remaining portion of the northwest half of the county is largely occupied by the Mississinewa moraine of the Erie lobe, which closely flanks the interlobate moraine. The inner or southeastern border of the Mississinewa moraine is followed more or less closely by Eel River. The portion of the county lying east and south of Eel River is largely plane surfaced, though occasional knolls and ridges of drift give it some diversity.

This county is preeminently a clay county, there being but limited areas in which sand or gravel is found at the surface or at slight depth. The drift to a depth of 50 to 60 feet or more is usually a compact till in which only weak wells can be obtained. The most conspicuous exception is a narrow belt along Eel River, scarcely more than a mile in width, in which deposits of sand and gravel appear at the surface, and strong wells are obtained at slight depth.

The thickness of the drift is known at Columbia City, the county seat, and at Larwell, a village about 10 miles west from Columbia City. At Columbia City the gas boring made on low ground near Eel River has 224 feet of drift, mainly sand. At Larwell the gas boring

made on an elevated part of the moraine has 365 feet of drift. At this point there is about 100 feet of till at the surface, below which the drift is mainly sand and gravel. In both wells large quantities of water were obtained before reaching the rock. That at Columbia City overflows. It is probable that in the extreme southeast corner of the county the drift is less than 100 feet.

Individual wells.—But few records of wells were obtained in this county, since the sections appear to differ but little in structure. The compact till is reported in the majority of wells in every township of the county. Occasionally considerable variety is found in the distance to the water beds within the limits of a single village, but as a rule no strong wells have been obtained above the general water stratum, 50 to 75 feet below the surface.

At Churubusco, in the extreme northeast part of the county, the deepest well is reported to be 80 feet, while several are 50 feet or more.

At Collins, 4 miles southwest of Churubusco, several wells are 75 or 80 feet, through till.

At Columbia City, which is situated near the Eel River valley, wells often reach the bottom of the till at 30 or 40 feet.

The deepest water well of which record was obtained is on the plain in the southeastern part of the county, and penetrates—

	Feet.
1. Till	67
2. Sand and gravel, with beds of till	130
3. Water gravel	5
Total	202

ALLEN COUNTY.

General statement.—Allen County is situated in the northeastern part of Indiana, on the east border. Fort Wayne is its county seat. It has the distinction of being the largest county in the State, having an area of 650 square miles.

The greater part of the county has a level surface, though there are two well-defined morainic belts which pass through it. The St. Marys moraine enters in the southeast part and follows the northeast border of the St. Marys River to Fort Wayne. It then finds its continuation northward on the east side of the St. Joseph River. The Wabash moraine enters the county near Zanesville, in its southwest corner, and passes thence northward to the old lake outlet near Aboit. North from the outlet its course is northeastward along the northwest side of the St. Joseph River. There is a narrow plain in southern Allen County between these two moraines, but in northern Allen County they are separated only by the valley of the St. Joseph River. A plain in the northwestern part of the county extends beyond its limits into Dekalb and Whitley counties. The plain in the eastern part of

the county, formerly covered by the glacial lake which discharged southwestward to the Wabash, has a very smooth surface, with only an occasional low ridge of sand or bar of gravel formed by the lake waters.

In the southern half of the county the thickness of the drift is very much less than in the northern half, though probably averaging not less than 75 feet. At Fort Wayne it is 60 to 125 feet or more. Near the north border of the county the drift exceeds 200 feet, two borings having reached that depth without entering rock. In the south part of the county it is in places but 20 or 30 feet.

In this county, as in Whitley, the greater part of the drift penetrated by wells is a compact till. Wells are, as a rule, more easily obtained than in Whitley County. Along the St. Joseph River there is a narrow belt of gravelly land. There is also a gravel plain of some extent in the northwest part of the county, near Huntertown, which connects the gravel deposits of the Cedar Creek valley with the gravel belt on Eel River, thus crossing the continental divide between the St. Lawrence and the Mississippi basins. It is needless to say that there is no ridge along this part of the divide.

Individual wells.—A well at the court-house in Fort Wayne, sunk in 1875 for artesian water, reached a depth of 3,000 feet, but its head fell short several feet of coming to the surface, 772 feet above tide. The drift at this boring is 88 feet. A boring for natural gas in the old lake outlet, north of the St. Marys River in Fort Wayne, at an elevation about 750 feet above tide, penetrates 96 feet of drift. One 3 miles west, also in the lake outlet, has 90 feet of drift. The waterworks of Fort Wayne are supplied from about fifty wells, some being in gravel at depths of 40 to 60 feet, others in rock at 250 to 450 feet. Abbott's gas-well boring in the eastern part of the city, at an elevation nearly 800 feet above tide, penetrates 106 feet of drift. In this, as well as several other borings in the vicinity of Fort Wayne, the lower portion of the drift is found to contain much sand and gravel. In one boring near the bank of the Maumee River Dr. Dryer reports a flowing well, depth not given, which upon a partial analysis shows hard water, with a trace of sodium chloride and a small amount of sulphureted hydrogen; also iron carbonate in measurable amount.[1]

Wells near the county infirmary, southwest of Fort Wayne, on the border of the lake outlet, obtain water at 25 or 35 feet. After penetrating a few feet of surface sand they are mainly through till. In a few cases the wells reach a depth of 60 feet.

In the portion of the county north of the lake outlet and west of the St. Joseph River there is usually but 20 or 30 feet of till to be penetrated before a strong stream of water is found in sand or gravel. Possibly a continuous sheet of gravel underlies that region at comparatively slight depth. In one case a boring near the north line of

[1] Sixteenth Ann. Rept. Indiana Geol. Survey, p. 127.

the county, after penetrating 20 feet of surface till, was carried 125 feet into sand without reaching its bottom.

Reference was made in the discussion of Dekalb County to several wells near Spencerville which have a depth of 60 to 100 feet. Some of these are located in northern Allen County. The well at Christian Hirsh's, 198 feet deep, is very near the county line. This well, after penetrating 70 feet of till, passed through 120 feet of fine sand before entering a material coarse enough to screen. Sand of such fineness is frequently a greater obstacle to well drillers than a solid blue till free from water.

Deep wells are more common in the northeastern part of the county than elsewhere, there being a heavy sheet of till on the moraine east of the St. Joseph River and also on the old lake plain. It is not rare to penetrate till 60 or 75 feet before obtaining water.

From Fort Wayne eastward to New Haven rock is usually encountered at 80 feet or less. In some cases wells are obtained at 25 or 35 feet in beds of gravel between the sheets of till. There are also places where wells may be obtained in the sand of the old lake outlet at depths of 20 feet or less.

At the village of New Haven the wells are obtained in gravel at a depth of about 30 feet. There is, however, a well at E. W. Green's, just east of the village, situated on the upper lake beach, which has the following section:

	Feet.
1. Beach sand and gravel	9
2. Blue clay	33
3. Gravel	3
4. Blue till	23
5. Cobble and gravel	5
Total	73

Another well at Mr. Green's, 55 feet in depth, penetrates 18 feet of surface sand, and is then through blue till to the bottom. There are two wells at Herman Schuelker's, in New Haven, each about 60 feet in depth, which are mainly till. The waterworks supply at New Haven is from a gas boring 300 feet in depth. In this boring rock was struck at 82 feet. At about 150 feet a strong flow of water was obtained, which rose nearly to the surface, and at 300 feet the head was increased to 11 feet above the surface. An analysis of the water is given elsewhere.[1]

A well at Robert Bell's, east from New Haven, near the State line, strikes rock at 60 feet, and obtains water at that depth.

The southeastern portion of the county usually affords strong veins of water at convenient depths, seldom more than 30 or 40 feet. The drift in that portion of the county is probably not more than 75 feet in average thickness.

[1] Eighteenth Ann. Rept. U. S. Geol. Survey, Part IV, p. 498.

In the southwestern and southern portions of the county records of a few wells were obtained which penetrate 20 or 30 feet of till before reaching a water gravel. Occasionally a well is sunk to a depth of 75 feet, largely through till. One well on the moraine in the southwest corner of the county, 102 feet in depth, is mainly through till. Another, 85 feet in depth, is also largely through till. Upon passing eastward from the moraine in the southwest township of the county tubular wells are found to decrease in depth, being 75 or 100 feet on the moraine and but 40 or 50 feet on the bordering plain.

ADAMS COUNTY.

General statement.—Adams County is situated on the east border of the State, immediately south of Allen. Its area is 330 square miles. Like Allen County, it has a large amount of very plane surface, whose monotony is broken by two moraines, the St. Marys and the Wabash. The St. Marys moraine crosses the northeast corner of the county, and occupies a belt 2 to 4 miles in width along the east border of the St. Marys River. The Wabash moraine traverses the southern and southwestern portion of the county, following the northeast border of the Wabash River, and has a breadth seldom exceeding 2 miles. The altitude of the southern portion of the county is somewhat higher than that of the northern portion, but the general descent in the 24 miles from south to north across the county amounts to scarcely 100 feet.

The moraines and also the plain tracts present a nearly unbroken sheet of till. There appear to be no definite gravel aprons or outwash deposits from the moraines. In places where the drift is thick considerable sand and gravel is found in its lower portion, but as a rule the drift deposits are thin, their average thickness being scarcely more than 50 feet, if the deep preglacial valleys are disregarded. Wells often reach rock at but 30 or 40 feet or less, and the shallow valleys of the St. Marys and Wabash, scarcely more than 30 feet in depth, have numerous rock outcrops along their courses in this county. The great depth of valley excavation prior to the drift deposition is shown by the gas-well boring at Geneva, in the southern part of the county, where 350 feet of glacial drift was encountered. Within a mile of the boring at Geneva rock outcrops occur at an elevation as high as the well mouth. Notwithstanding the great depth of these preglacial valleys, they are so completely filled that no surface indications of their courses can be seen.

Individual wells.—Along the St. Marys moraine and the plain east of it, in the northeastern part of the county, the depth of wells ranges from 20 to 50 feet, mainly through till.

At Decatur rock is struck at the court-house well at 40 feet. It penetrates till, with the exception of a few feet of sand at the bottom. Several wells in the city obtain their water supply from this bed of

sand and gravel above the rock. The city waterworks obtain a supply from limestone at 250 feet.

At Pleasant Mills, near the east border of the county, wells are 20 to 35 feet in depth, mainly through till. They usually obtain water in a bed of sand or gravel, but a few enter the rock.

On the plain south and west from the St. Marys River records of several wells were obtained which enter rock at 50 or 60 feet. They usually penetrate from 35 to 50 feet of till, beneath which a bed of sand is found, which, if not of too fine texture, is made the source of water supply, but if very fine it is cased out, and water is obtained from the underlying rock. On portions of this plain rock is encountered at 20 to 25 feet.

On the Wabash moraine, in the southern part of the county, records of two wells were obtained in sec. 32, T. 25, R. 15 E., which enter rock at 51 and 60 feet. They each penetrate 35 or 40 feet of till, below which is sand. A well on the moraine in section 31 of the same township enters rock at 70 feet. It penetrates till 52 feet, below which is sand and gravel.

Along the Wabash River wells are usually obtained at 15 or 20 feet, either at the surface of the rock or at slight depth in it.

At Geneva, which is situated near the Wabash River, the wells usually obtain water in gravel below till at about 35 feet. A few are sunk into limestone and have a depth of 80 feet. The gas-well boring, as above noted, penetrated 350 feet of drift. Of this, the upper 80 feet was principally till; the remaining 270 feet was mainly sand and gravel.

On the plain southwest from the Wabash River rock is usually encountered at but 20 or 30 feet. The majority of wells, however, are obtained without penetrating the rock.

WELLS COUNTY.

General statement.—Wells County is situated immediately west of Adams and south of Allen County, in the northeastern part of the State. It has an area of 357 square miles. Its topography is quite similar to that of Adams County, there being a plain surface except in two moraines, one of which crosses the northeastern portion of the county and the other the southwestern. The one in the northeastern part is the continuation of the Wabash moraine of Adams County. It follows the northeastern border of Wabash River to about the middle of the county, where it turns north away from the river and traverses Allen County, as noted above. The moraine which crosses the southwestern corner follows the northeast border of Salamonie River and receives the name Salamonie from that stream. Neither of these moraines much exceed 2 miles in average width in their course through this county. There is also a slight ridging of the drift along

the northeast border of Rock Creek, parallel to and midway between the two moraines just mentioned. Its relief is, however, but 15 or 20 feet, or scarcely half as great as the relief of either of the moraines mentioned. The streams of this county, like those of Adams, are flowing in small, shallow valleys, cut but 20 to 40 feet into the plains.

The drift is very similar to that of Adams County, being a somewhat uniform sheet of compact till at surface, with thin beds of sand included in or underlying it. The thickness of the drift is also moderate, rock being struck at many places at 30 to 50 feet, and occasionally at less depths. The average thickness for the county, unless greatly affected by concealed deep valleys, probably does not exceed 50 feet. There are no surface indications of deep valleys traversing the county, nor have borings shown their presence. The deep borings, however, are not sufficiently numerous to afford much knowledge of the topography of the rock surface.

Individual wells.—Wells along the Wabash moraine, in the north part of the county, usually penetrate but 50 or 75 feet of till, and tubular wells are usually put down to these depths. The dug wells obtain moderate amounts of water from local beds of gravel or sand in the till at much less depth. At Kingsland, on the crest of the moraine, a record of one well was obtained, which enters rock at 80 feet, but another well of the same depth does not reach rock; both are mainly through till.

West of the Wabash moraine rock is usually found at 50 to 70 feet, while in the vicinity of Uniondale it is struck at 20 to 40 feet. The tubular wells often enter the rock. Dug wells usually obtain supplies of water in the lower portion of the drift.

Near the eastern border of the county the drift on the moraine is about 100 feet in thickness, and several wells in that vicinity are 60 to 100 feet in depth. On the plain north of the moraine wells are usually obtained at less than 50 feet.

Along the Wabash River there are numerous outcrops of rock, but wells are ordinarily obtained above the rock at depths of 20 feet or less.

At the city of Bluffton, the county seat, the supply for the waterworks is obtained from wells drilled into the rock to a distance of 150 to 300 feet.

On the plain southwest from the Wabash River wells are usually obtained at 40 feet or less in beds of sand or gravel below the till. Occasionally a well is sunk to a depth of 60 or 75 feet.

On the Salamonie moraine the wells range from 20 feet up to 75 feet or more. They are principally through till.

Along the Salamonie River, and on the plain west of the river, wells are seldom more than 30 feet in depth, and are usually through till to the water vein near the bottom.

HUNTINGTON COUNTY.

General statement.—Huntington County is situated in northeastern Indiana, west of Wells and the southern portion of Allen County, and has an area of 380 square miles. Huntington is its county seat. The greater part of this county is a smooth, sloping plain, standing 800 to 900 feet above tide. The Salamonie moraine, which enters it from Wells County in the southeastern corner, becomes scarcely traceable near the center of the county, and no other moraine of prominence is found within the limits of the county. The valleys are small, with one exception, that of the lake outlet, which joins the Wabash at Huntington. This outlet has a depth of 40 to 75 feet and a breadth of 1 to 2 miles throughout its course in the county, whereas the Wabash, above its junction with the outlet, and also the Salamonie, have valleys scarcely one-eighth of a mile in average width and of less depth than the lake outlet.

The elevation of the rock surface decreases gradually northward from the southern boundary of the county to the lake outlet. North of the lake outlet it appears to drop down rapidly. The drift is comparatively thin in the portion of the county south of the outlet, there being seldom so much as 100 feet encountered in wells. North from the outlet the thickness of drift is 150 to 200 feet or more.

In Huntington County, as in Wells and Adams, the drift is mainly a compact till. Wells are obtained either in local deposits of gravel and sand within the till or more extensive deposits which appear to prevail near the base of the drift.

Individual wells.—Wells on the plain north of the Wabash outlet have, in a few cases, entered rock at about 140 feet after penetrating a nearly solid sheet of till. Ordinarily, the wells are but 50 to 100 feet and encounter no rock.

In the city of Huntington, on the uplands bordering the lake outlet, wells are frequently obtained at about 30 feet in gravel below till. Along the outlet they are usually sunk into the limestone, which there outcrops quite extensively. The waterworks wells are sunk into the limestone to a depth of about 100 feet. Although there are 11 wells in use, the supply is insufficient and some water is pumped from the river.

Above Huntington, in the vicinity of Roanoke, wells in the old lake outlet are often obtained without entering rock, at depths of 10 to 25 feet. One well near Roanoke enters rock at 36 feet.

In the vicinity of New Lancaster, on the borders of the Salamonie River, gravel is more abundant than elsewhere along the valley and wells often obtain water without penetrating till. Between New Lancaster and Andrews wells commonly penetrate 20 to 40 feet of till.

At Andrews, the wells are usually carried into the limestone to depths of 60 to 150 feet, and occasionally to over 200 feet. The analy-

sis of water from a well in this village, 214 feet in depth, is given elsewhere.[1] The water is shown to be slightly saline as well as hard. It also contains much sulphureted hydrogen.

In the vicinity of Warren several flowing wells have been obtained in limestone on low ground along the Salamonie River at a depth of 65 to 100 feet. The head is sufficient to carry the water only 5 or 6 feet above the surface. The water is decidedly chalybeate.

WABASH COUNTY.

General statement.—Wabash County is situated in the north-central portion of the State, with the city of Wabash as its county seat. Its area is 430 square miles. The eastern border of the county is occupied throughout its entire length by the Mississinewa moraine. The northwestern part of the county is occupied by the Erie-Saginaw interlobate moraine, the southeast border of that moraine being near the valley of Eel River. The portion of the county west and south from these moraines is a till plain. The morainic ridge on the east border of the county, as well as the interlobate moraine, rises above the 800-foot contour, but the greater part of the plain in the county falls below 800 feet, and on the immediate border of the Wabash scarcely exceeds 700 feet. The valley of the Wabash passes through the county a little south of the center. Occupied as it was by the lake outlet, it is very much larger than the other valleys of the county and the valleys of similar-sized streams in the newer drift area. The average width is fully 1 mile and the depth 50 to 100 feet.

In Wabash County, as in Huntington, the general elevation of the rock surface is much higher south from the Wabash River than it is north, and as the altitude of the northern portion is fully as great as that of the southern, the drift deposits of the northern portion are very heavy. The drift of the southern portion is about like that of counties to the east and probably falls below an average of 100 feet. The drift in the northern portion probably in places exceeds 300 feet, the thickness at North Manchester, in Eel River Valley, being 274 feet. In the southern portion, however, there are valleys deeply filled with drift that show a rock surface about as low as that of the northern portion of the county. Such a valley was brought to light by the boring at Lafontaine (Ashland post-office), where the drift is found to be 300 feet in thickness.

Wabash County resembles the counties to the east in carrying a somewhat uniform sheet of compact till. The only gravelly districts worthy of note are a narrow belt along the borders of Eel River and terraces in the valley of the Wabash.

Individual wells.—A boring for natural gas at North Manchester penetrates 274 feet of drift, mainly sand. The drift within the limits

[1] Eighteenth Ann. Rept. U. S. Geol. Survey, Part IV, p. 498.

of that village, however, varies considerably. Several flowing wells along Eel River valley penetrate till to a depth of 50 to 70 feet, beneath which is a sheet of water with a head sufficient to rise 10 or 12 feet above the surface. The waterworks supply is from flowing wells 100 feet in depth. In the higher portion of the village wells are ordinarily obtained at 30 or 35 feet, without penetrating much till, but in a few instances they are carried to depths of 100 or 115 feet, largely through till.

On the Mississinewa moraine, east and southeast from North Manchester, wells are often in till to a depth of 100 feet or more before obtaining a strong vein of water. One well, 4 miles east of North Manchester (in sec. 12, T. 29, R. 7 E.), penetrated 156 feet of till.

On the plain between Eel River and the Wabash and west from the Mississinewa moraine wells usually penetrate till to a depth of 30 or 40 feet to obtain a strong vein of water. On the north side of Eel River, west from North Manchester, the interlobate moraine usually presents 50 feet or more of compact till at its surface, through which many wells have been sunk.

At Laketon, in the valley of Eel River, below North Manchester, a well 125 feet in depth is mainly through sand. It is thought by the residents of that village that the sheet of sand passes northward beneath the till of the moraine, but there have been few deep wells to test the value of this opinion.

At the city of Wabash wells are often obtained in the valley at depths of 15 to 25 feet without reaching the bottom of the gravel. A better supply is, however, obtained at about 100 feet in the limestone. Some objection is offered to the water from the limestone because of its extreme hardness. For that reason the waterworks are supplied largely from drift wells. The wells are located in the valley of Treaty Creek, south of the city, and are overflowing. The depths range from 42 to 55 feet.

On the Mississinewa moraine, south of the Wabash, several wells have been put down to depths of 95 or 100 feet or more through till before obtaining an adequate supply of water, but as a rule water may be obtained at less than 50 feet.

On the plain west of the Mississinewa moraine, in southern Wabash County, till is usually penetrated to a depth of 25 to 40 feet or more.

At Lafontaine, in the south part of the county, the gas boring penetrates 300 feet of drift, but rock outcrops within a short distance, both above and below Lafontaine, in the bluffs of the Mississinewa River. Wells are usually obtained at Lafontaine and at other points along the Mississinewa, in the southern part of the county, at depths of 25 or 35 feet. Gas borings in the vicinity of Somerset, in the southwest corner of the county, show the drift to have a thickness ranging from 35 up to about 100 feet the lower portion of which is a water-bearing sand or gravel.

In the Seventeenth Report of the Indiana Geological Survey many records of wells are published which have a depth of only 10 to 40 feet. With these are occasional records of deeper wells. One near New Madison (sec. 11, T. 29, R. 7 E.), 207 feet in depth, strikes limestone at 181 feet. It penetrates till 160 feet, below which is 21 feet of sand. Two other wells in section 26 of the same township penetrate a similar amount of till, and obtain water in sand or gravel at 164 and 185 feet without entering rock.

It is stated that wells occasionally enter rock at 70 or 75 feet on farms 5 miles north of Lagro, but a well in that vicinity, on the farm of Christopher Speicher, strikes no rock at a depth of 156 feet. It is mainly through blue till, there being a thin bed of gravel at 80 to 84 feet and another at 150 to 156 feet.

Records of two deep wells in the southwest township of the county are reported as follows: On farm of Jacob Thomas, depth 64 feet, till except 4 feet of water-bearing gravel at bottom; on farm of L. Waggoner, depth 96 feet, till 80 feet, below which are alternations of gravel, sand, and blue mud, to a limestone at bottom.

On the farm of John H. Pefley, near the south bluff of the Wabash River, in sec. 18, T. 27, R. 8 E., a well 62 feet in depth is reported to have barometric properties of a marked character, there being an inrush of air in fair weather and an escape of air in foul weather. A whistle, made of two convex disks with a hole in the center, attached to a gas pipe screwed into the base plate of the pump may be heard frequently at the distance of one-half mile, and makes apparent the force of the current of air. It is probable that air spaces in the sand offer a medium for the inflow of air to correspond with the changes of atmosphere outside the well. The section of the well is as follows:

	Feet.
1. Soil and yellow clay	7
2. Sandy blue clay	24
3. Blue hardpan clay	1½
4. Dry sand	8
5. Sandy blue hardpan	12
6. Water-bearing blue hardpan	9½
Total	62

MIAMI COUNTY.

General statement.—Miami County is situated in the north-central part of the State, immediately west of Wabash County, with Peru as its county seat. Its area is 360 square miles. The broad Wabash Valley traverses it nearly centrally from east to west and, as in Wabash County, separates a district of thin drift on the south from one of thick drift on the north. The northern portion is even more elevated than the southern, but the rock surface is much lower in the former district. The portion of the county south of the Wabash is

nearly all plane surfaced, and so, also, is much of the district between the Wabash and Eel rivers. That north of Eel River is strongly morainic, and embraces part of the large Erie moraine, which, with the Maxinkuckee moraine of the Saginaw lobe, forms the interlobate moraine of northeastern Indiana and southeastern Michigan. The drift is composed largely of till in the plains, but in the moraines there are knolls of gravel and sand associated with the till knolls, as well as extensive deposits of sand and gravel in the deeper portion of the drift.

Individual wells.—A gas boring 2½ miles north of Peru penetrates 318 feet of drift, a large part of which is water-bearing sand and gravel. Neighboring wells for water usually obtain an abundant supply after penetrating till 30 to 40 feet. One well, however, in sec. 29, T. 28, R. 5 E., penetrated 90 feet of till before obtaining water.

In the city of Peru there are few wells drilled into rock, although there are numerous rock outcrops in the vicinity of the city. The average depth of the wells is about 30 feet, with a range from 15 up to 60 feet. They penetrate either a loose alluvial deposit before entering gravel and sand or pass immediately into gravel and sand. There is, therefore, a liability of contamination of the water from cesspools or other sources. The city water supply is pumped from the Wabash River.

At Bunker Hill a sheet of till 25 to 40 feet in thickness is usually passed through before water-bearing sand or gravel is reached. In one of the gas wells at Bunker Hill the drift was 68 feet, in another 84 feet; in both the lower half was largely sand and gravel.

A gas boring east of Bunker Hill, in sec. 21, T. 26, R. 5 E., at an altitude of 175 feet above the Wabash at Peru, penetrates 60 feet of drift, of which 54 feet is till and the lower 6 feet gravel.

At Amboy the wells penetrate about 15 feet of till, beneath which is a water-bearing gravel extending to the rock. In that vicinity rock is struck at 35 to 50 feet.

At Xenia (Converse post-office) the dug wells are 10 to 20 feet in depth, in gravel beneath a sheet of till. The drift in that vicinity is variable in depth, ranging from 25 up to 100 feet or more in thickness. A few wells are drilled into the rock to depths ranging from 100 to 400 feet. From the deep wells the head is sufficient to bring to the surface water which is reported to be of excellent quality.

In the southwestern part of the county wells are often 50 to 70 feet through till, though shallower wells are usually obtained.

A well at Denver, in the northern part of the county, is noted by Mr. Gorby,[1] which penetrates 125 feet of sand and gravel and reaches no rock.

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[1] Sixteenth Ann. Rept. Indiana Geol. Survey, p. 178.

CASS COUNTY.

General statement.—Cass County is situated in the north-central part of the State, the city of Logansport being its county seat. Its area is 420 square miles. The valley of the Wabash traverses it nearly centrally from east to west. The portion south of the Wabash is a comparatively smooth till plain. The portion north of the Wabash is largely morainic, though there is a plain in the extreme northwest corner of the county. There is not the conspicuous descent of the rock surface from south to north that appears in the three counties along the Wabash east from this county. In the immediate vicinity of the Wabash the drift is thin, but on the upland, both north and south of the river, a thickness of 75 to 100 feet or more is found. The drift is very largely till, as in counties to the east.

Individual wells.—At Royal Center, in the northwest part of the county, the oil-well borings enter rock at about 110 feet. The water wells are about 40 feet, though having a range from 15 up to 110 feet. They usually penetrate the following series:

	Feet.
1. Surface clay	4 to 6
2. Gravel	5
3. Blue till, extending to the water-bearing gravel	40
Total	50

At Logansport wells range in depth from 12 to 80 feet, but the majority are about 40 feet. The rock surface being uneven, wells in some cases reach a depth of 40 feet in drift, while in others they enter limestone at 10 or 20 feet. The drift in this city being composed mainly of gravel and the water surface being but a few feet below the well mouth, there is much danger of contamination. The city waterworks obtain the supply in part from springs and in part from Eel River.

On the Wabash bluff, south from Logansport, wells are about 40 feet in depth, the upper half being through till and the lower in gravel.

A well on the north bluff of Wabash River, near Logansport, sec. 27, T. 27, R. 2 E., was largely through sand and gravel to a depth of 90 feet, and struck wood and leaves near the bottom.

In the vicinity of Lake Cicott, in the western part of the county, there are sand deposits on the north bluff of the Wabash which in some cases afford water for wells at a depth of 15 feet. Wells usually, however, penetrate the underlying till.

At Walton, in the southeastern part of the county, the drift is about 80 feet, and is largely till. At Galveston the drift in a valley 20 feet or more below the level of the railway station is shown by a gas boring to be 41 feet in thickness. The lower portion contains much water.

WHITE COUNTY.

General statement.—White County is situated in the northwestern part of the State, immediately west of Cass County, its county seat being Monticello. It has an area of 500 square miles. With the exception of a few drift ridges in its southern portion and occasional sand ridges in its northern portion, it has a plane surface. The drift ridges are most conspicuous immediately east of Chalmers. It is at this point that the large Erie moraine, which has been referred to as occupying the northern portion of Miami and Cass counties, makes a curve to the south. A smaller and perhaps older moraine, formed probably by the Saginaw lobe, leads from near Chalmers westward through White and Benton counties. The Tippecanoe valley in its course across White County deepens from a comparatively shallow ditch near the north border of the county to a trench 75 or 100 feet in depth at the south. Its breadth is but a few rods greater than the stream, and is in strong contrast with the large valley of the Wabash, into which it discharges.

The drift in the northwestern portion of this county, like that of adjacent portions of Pulaski and Jasper counties, is very thin, and the majority of wells enter rock at 10 to 20 feet, or even less. In the southeastern portion of the county there is a heavy deposit of drift, 200 feet or more in thickness.

Individual wells.—At Monon, in the north part of the county, rock is entered at from 3 to 30 feet. Wells are usually about 40 feet, though they range from 20 to 200 feet in depth. The limestone from which the water is obtained contains a sufficient amount of iron pyrites to affect the water appreciably, though not sufficient to render it unfit for drinking.

At Monticello, the county seat, wells are usually obtained at 20 or 30 feet, in gravel below till. Tubular wells are somewhat deeper, the deepest being about 140 feet. The city water supply comes from a large well of moderate depth, but thought to be beyond the reach of surface contamination. The gas-well boring at this place penetrated 205 feet of drift, largely till.

At Reynolds, in the central portion of the county, there are a series of sand ridges, in which water is often obtained at a depth of 15 or 20 feet, or even less. Tubular wells reach a depth of 75 to 120 feet without entering rock. One of the tubular wells, at Mr. Van Voorst's, 56 feet in depth, is reported to have entered a black muck at the base of the sand, about 30 feet from the surface, 6 or 7 feet in thickness, beneath which is a blue clay about 15 feet thick, extending to the water-bearing gravel at bottom. A well opposite the post-office found a similar muck at the bottom of the sand at 20 feet, and entered gravel beneath it at 25 feet. Wells not infrequently encounter muck below the sand in this region. A well in the south part of Reynolds, 120

feet in depth, encountered either a bowlder or a rock ledge, which prevented further boring.

Among the deepest wells in the county is William Owen's, about 6 miles southwest of Reynolds, 190 feet in depth. It entered rock at 30 feet. Inflammable gas was found at about 145 feet. Wells in that vicinity often strike rock at 20 or 30 feet. The thick drift seems to set in immediately east from a line running south from Reynolds through Chalmers. In Chalmers rock is struck at about 90 feet, but at Albert Gosley's, 1½ miles east of Chalmers, no rock was found at 150 feet; and a well at J. N. Bunnell's, a mile southeast of Reynolds, strikes no rock at 160 feet.

On the drift ridge west from Chalmers rock is usually struck at 75 or 80 feet. On the plain north of the ridge it is struck at 20 to 40 feet. On the south slope of the ridge, in sec. 5, T. 25, R. 5 W., rock is struck at 54 feet and water obtained at 75 feet. One well, however, on the moraine near the west line of the county, failed to reach rock at 113 feet. The drift, both on the plain and in the morainic ridges in the southern part of White County, appears to be mainly till.

BENTON COUNTY.

General statement.—Benton County is situated on the western border of the State, immediately south of Newton and Jasper counties and west from White County. It has an area of 503 square miles, and the village of Fowler is its county seat.

This county is occupied by several somewhat prominent drift ridges. In the north tier of townships there is a sharp drift ridge, scarcely a mile in average width, but 25 to 75 feet in height, passing entirely across the county and forming the south border of a plain which is drained by the Iroquois River. A few miles farther south a prominent ridge enters Benton County from the west and passes eastward, bearing slightly north, to the village of Fowler, where it abruptly terminates. This ridge has a breadth of 3 or 4 miles and a relief of 60 to 75 feet or more above bordering plains. On the south border of the county is a third ridge, which passes eastward to the vicinity of Oxford, where it swings abruptly to the north and terminates immediately east of Fowler. This ridge has about the same breadth as the one north of it, but scarcely so great relief. Aside from the three main ridges just mentioned, there are, northwest from Fowler, a series of sharp drift knolls, 25 to 50 feet in height, filling a portion of the plain between the north and middle ridges. Notwithstanding the occurrence of several prominent ridges, the general elevation of the county is remarkably uniform, the variations in elevation being about that of the relief of the ridges. Nearly the entire county lies between the contours of 700 and 800 feet above tide. A point near Fowler, on a sharp gravel knoll, reaches 857 feet, said to be the highest in the county.

The thickness of the drift in this county is found to be very great in the southern and western portions, in one place exceeding 400 feet. But in the northern and eastern portions of the county, including nearly half its area, the drift is seldom found to exceed 100 feet. The surface portion of the drift appears to be generally a compact till, but the deeper portions, so far as tested by well borings, consist mainly of sand and gravel.

Individual wells.—The following list of well sections includes several which have already been published,[1] but the majority were personally obtained from well drillers or owners of wells.

The drift in northwestern Benton County, north from Sugar Creek, is shown by several wells to be a compact till to considerable depth, but along Sugar Creek and on the plain to the south much sand is encountered.

At Earl Park a well, bored by P. M. Crane, penetrates—

	Feet.
1. Soil and yellow till	18
2. Blue till	40
3. Fine gray quicksand	20
4. Blue till	12
5. Limestone	12
Total	102

The water supply is from the limestone. At Raub's warehouse, in Earl Park, limestone was struck at 80 feet, and water obtained at 110 feet. The drift was entirely till. Rock is quarried on Sugar Creek, 1 mile north of Earl Park, on ground but 40 to 50 feet lower.

In sec. 1, T. 26, R. 9 W., near the north line of the county, Mr. Schlautenhofer has a well 108 feet in depth, which obtained water at that depth beneath a bed of dark material thought to be coal. Shale was struck at 70 feet.

In sec. 7, T. 26, R. 8 W., a well 109 feet in depth has the following section:

	Feet.
1. Soil and yellow clay	6
2. Blue clay	44
3. Sand	2
4. Blue clay	57
Total	109

Other wells on the same section are obtained at 35 or 40 feet in a bed of gravel beneath the blue clay.

On Mr. Raub's farm, 2 miles east of Earl Park, water is obtained in limestone at 54 feet. The drift, 50 feet, is entirely till.

On the crest of the north drift ridge, in sec. 20, T. 26, R. 7 W., Mr. J. W. Swan has a well 116 feet in depth, which is thought to have struck sandstone at 82 feet, though it is reported to obtain water from gravel

[1] Fifteenth Ann. Rept. Indiana Geol. Survey, pp. 205-220.

at the bottom. The drift was till to a depth of 75 feet. Another well, only 150 yards distant, penetrated till to a depth of 82 feet without entering rock. On the south slope of the moraine Mr. Swan made a well which obtained water beneath the till at 25 to 27 feet. Another well on the south slope penetrated beds as follows:

	Feet.
1. Till	21
2. Cemented gravel	10
3. Water gravel	3
Total	34

Two miles east from Mr. Swan's, in the western edge of Gilboa Township, a well on the moraine strikes rock at 173 feet. It is reported to be mainly blue till with occasional beds of sand. Water was obtained at a depth of 196 feet. There is a quarry on Pine Creek, just south of this moraine, in sec. 28, T. 26, R. 7 W., at an elevation perhaps 75 feet lower than the well mouth. The rock surface, therefore, varies about 100 feet in elevation.

In the eastern part of the county several wells enter rock at 50 feet or less, and there is a quarry on Pine Creek just north of the village of Aydelott.

A well near the northern terminus of the southernmost of the three ridges above mentioned, in sec. 15, T. 25, R. 7 W., enters rock at 55 feet and obtains water at 60 feet. Another well, in sec. 10 of the same township, 85 feet in depth, enters rock at 72 feet. In both wells the drift is a compact blue till.

At Fowler the waterworks' supply is obtained from wells about 175 feet in depth. They enter rock at 130 feet. The water rises within 25 feet of the surface and the wells are estimated to yield 150 gallons per minute. Several other deep wells have been made in Fowler and vicinity, which show a considerable variation in the elevation of the rock surface. A well at Mr. Van Nata's, in the west edge of the village, enters rock at 91 feet, after penetrating a nearly solid bed of till. A neighboring well, bored by Mr. Fowler, only 300 yards distant, reached a depth of 150 feet without encountering rock. In this well the upper 100 feet is till, below which is gravel and sand. The well at the post-office in Fowler strikes no rock at 160 feet. The drift is reported to be mainly sand. At the Tremont Hotel a well 104 feet in depth strikes no rock and is mainly through sand. The gas-well boring in Fowler, one-fourth mile north of the railway station, strikes rock at 158 feet. In all these wells the surface altitude is very uniform, there being scarcely 10 feet variation. Wells for a short distance north and east of Fowler are obtained at 20 to 30 feet in sand and gravel below till.

On the farm of Mrs. Sumner, at Sugar Grove, 6 miles southwest of Earl Park, rock is struck at 41 feet and water obtained at 47 feet.

A few miles southwest of Fowler, on the middle drift ridge noted

above, several deep wells have been made. Mr. William Bennett, sec. 33, T. 25, R. 9 W., has had several wells sunk to a depth of about 150 feet, and one to a depth of 264 feet, without reaching rock. The drift is mainly till to a depth of 150 feet, below which is sand. The following section is from the well at Mr. Bennett's residence:

	Feet.
1. Soil and yellow till	20
2. Blue till	27
3. Hard gray till	12
4. Greenish-gray till	81
5. Fine gravel	4
6. Greenish till	18
7. Coarse gravel, with water	8
Total	170

A well at Lawrence Broes's, sec. 4, T. 24, R. 9 W., 260 feet in depth encounters no rock, and has a section similar to Mr. Bennett's. A well 3 miles north of Ambia, on the crest of the moraine, penetrates—

	Feet.
1. Yellow till	14
2. Blue till	80
3. Fine, dry sand	20
4. Blue till	46
5. Gravel, with water	1 to 2
Depth to water	160

At John Shilling's, 4 miles northeast of Ambia, near south border of the moraine, a well 114 feet in depth penetrates—

	Feet.
1. Soil and sand	28
2. Blue till	50
3. Quicksand	16
4. Blue till	20
Gravel at bottom.	
Total	114

Wells along the south border of the middle ridge are usually obtained at shallow depths, but occasionally reach a depth of 50 to 65 feet. They often encounter sand and gravel near the surface. Thus, at James Siddon's well, about 2 miles north of Talbot, the drift is mainly sand to a depth of 24 feet, below which there is a bed of blue till 40 feet in thickness, water being obtained in gravel at 65 feet. Another illustration is found in the well at Mr. A. K. Dill's, 3 miles north of Boswell. This well penetrates a loose gravel 18 feet, below which is a thin bed of blue clay, which in turn is underlain by a cemented gravel 40 to 45 feet in thickness, extending to the water gravel at 65 feet.

In the southern tier of townships several borings have been made which show 300 to 400 feet of drift. At Otterbein, however, a boring 212 feet in depth strikes rock at 132 feet, and about 5 miles north of

Otterbein rock is struck at 80 feet. Among the borings showing a large amount of drift are the following:

W. J. Templeton's boring for artesian water, about three-fourths of a mile northeast of Templeton, reached a depth of 300 feet without entering rock. The drift is mainly till, but sand in its lower part furnishes water, which rises nearly to the surface, 675 feet above tide.

A boring by W. J. and L. Templeton, on their farm in sec. 32, T. 24, R. 8 W., about 5 miles southwest of Oxford, made with a view to obtaining coal, penetrated 372 feet of drift, as follows:

	Feet.
1. Yellow till	12
2. Blue till	115
3. Cemented gravel	25
4. Yellow till and gravel	110
5. Black material, called shale	10
6. Clay and sand	100
Total	372

The well was continued to a depth of 537 feet, or 165 feet into the rock, which is mainly limestone.

A boring for gas on Joseph Atkinson's farm, about 1 mile east of the Templeton well, penetrated 410 feet of drift. A small amount of gas was found in the drift at a depth of 40 feet.

A well in the village of Talbot, 310 feet in depth, strikes no rock; the upper 60 feet is till, the remainder mainly sand.

In addition to the borings showing a very deep drift there are several others worthy of note in this southern tier of townships. A well made by W. J. Templeton, 2 miles east of Templeton, 177 feet in depth, penetrates—

	Feet.
1. Yellow till	12
2. Blue till, with thin sand beds	75
3. Cemented gravel	20
4. Yellow clay and sand	70
Total	177

J. D. Stengle's well at Templeton penetrates 60 feet of till, beneath which is water-bearing sand. Depth of well 80 feet. A well 2 miles south of Boswell penetrates—

	Feet.
1. Yellow till	13
2. Blue till	34
3. Quicksand	20
4. Gravel	66
Total	133

A well on Samuel Dove's farm, immediately east of Boswell, 185 feet in depth, strikes no rock.

At the several villages along the Lake Erie and Western Railroad wells are usually obtained at 20 feet or less, but, as indicated above,

occasional wells are much deeper. Many wells in Templeton obtain water at 20 or 30 feet. They enter blue till at about 6 or 8 feet. At Oxford wells are usually but 14 to 20 feet in depth, though occasionally 80 or 90 feet. In the east part of the village a flowing well has been obtained at a depth of 55 feet. It has a head about 5 feet above the surface. The water is strongly chalybeate. At Ambia, records of two wells were obtained which slightly exceed 100 feet in depth. They are mainly through blue till.

WARREN COUNTY.

General statement.—Warren County is situated on the west border of the State, immediately north of the Wabash River, with Williamsport as its county seat. It has an area of 360 square miles.

Like Benton County, which borders it on the north, this county is traversed by several conspicuous ridges of drift. Along its northern border is the southernmost of the ridges described in the account of Benton County. It has a breadth of 2 or 3 miles and a relief above the plain on the south of 40 to 50 feet or more. A few miles southeast of this ridge is a larger one, which enters the State near State Line village, passes northeastward nearly to Williamsport, and there turns north along the west side of Pine Creek. This ridge is 3 to 6 miles in width and has a relief of 30 to 60 feet or more above bordering plains on the north and south. East from Pine Creek are two ridges trending from northwest to southeast, extending from the valley of the creek to the valley of the Wabash, a distance of 8 or 10 miles. They are each a mile or more in width, and stand 30 or 40 feet above the bordering plains. The narrow plain between them is scarcely 1 mile in average width. The extreme northeastern part of the county is a plain. It is estimated that fully one-half the area of the county is occupied by the drift ridges.

The surface portion of the drift throughout the county is usually a compact till, though the portion east from Pine Creek becomes gravelly in limited areas. Along the Wabash there are conspicuous gravel terraces below Williamsport. Above that city the valley is too narrow for extensive development of terraces. The narrowness is due to the resistant rock strata in which the stream has cut its passage. It is, however, seldom less than one-half mile in width.

For some distance north from the Wabash, unless it be at the extreme eastern border of the county, rock is encountered at comparatively slight depth, seldom more than 100 feet; but along the northern border of the county it is probable that the drift, like that of the adjoining portion of Benton County, is 300 to 400 feet or more in thickness.

Individual wells.—But few well records have been obtained in this county, owing partly to the fact that wells are generally obtained at comparatively slight depth.

At Williamsport, the county seat, wells vary greatly in depth, there

being a range from 14 feet up to about 100 feet. In a portion of the city rock is struck at 10 to 15 feet, but there are places where the drift attains a thickness of 85 feet. A boring for gas at this city 1,540 feet in depth found fresh water at a depth of 65 feet in great quantity; also at about 165 feet. From the latter depth water rises within 32 feet of the surface. Salt water was struck at about 1,200 feet. Gas not being obtained, the salt water was shut off, and the fresh water is thus available for water supply. The well is estimated to yield 20 gallons per minute.

On the Wabash terrace below Williamsport, which stands about 100 to 110 feet above the river, several wells have been sunk to the level of low water in the river. They are through gravel or sand their entire depth. The water rises and falls with the rise and fall of the river.

A boring for coal at West Lebanon penetrated a soil containing wood and leaves beneath the blue till at a depth of 140 feet. Rock was entered a short distance beneath this soil. About a mile southeast from West Lebanon, on ground nearly 100 feet higher, rock is struck at a depth of only 60 feet.

TIPPECANOE COUNTY.

General statement.—Tippecanoe County is situated somewhat north of the middle of the western part of the State, with Lafayette, the county seat, near its geographic center. It has an area of 500 square miles. The greater part of the surface is plain or but gently undulating. There are, however, in the southern half a number of sharp gravelly knolls and ridges, which in places constitute a nearly continuous belt. The most conspicuous one, known as High Gap Ridge, leads from Culver Station westward past Taylor and West Point to the vicinity of the Fountain County line. It is, however, less than a mile in width, and the height of the ridges and knolls seldom exceeds 50 feet. The most conspicuous topographic feature of the county is the troughlike valley traversed by the Wabash River. The valley proper has a depth of more than 100 feet. From its borders there is a gradual rise both to the northwest and southeast—to an altitude in the northwest more than 200 feet above the river, and in the southeast to fully 300 feet.

With the exception of the sharp gravelly knolls referred to above, the surface portion of the drift is composed largely of compact till. The wells of the county usually find water at convenient depths, seldom penetrating so much as 80 feet. The lower portion of the drift, so far as tested by deep borings and by exposures along the Wabash and its tributaries, is largely sand and gravel.

The thickness of the drift varies greatly, partly because of difference in surface elevation, but more largely because of inequalities of the underlying rock surface. In the western part of the county, in

the vicinity of the Wabash River, rock ledges rise to a height of 50 to 100 feet or more above the stream, and are well exposed on Flint Creek and Indian Creek. In the northeastern part of the county, also, there are rock exposures on the borders of the Wabash and the lower course of Sugar Creek. Between these exposures, occupying the central portion of the county, there is a deeply filled basin, with drift 300 feet or more in thickness. This appears to be part of a great valley or trough which leads westward across southern Benton County.

To sustain the view that a deeply filled valley extends westward across northern Tippecanoe County, two well sections in the northwestern part of the county are cited. One, in sec. 26, T. 24, R. 6 W., reaches a depth of 176 feet without encountering rock; another, in sec. 18, T. 24, R. 5 W., strikes no rock at a depth of 126 feet. Toward the south, near the Wabash River, the rock appears in valleys of streams at a higher level than the botton of these wells. Passing northward into White County the rock appears at higher level than at these wells. It seems probable that the deepest portion of the valley passes near Dayton and Lafayette and thence north of west across the northwest part of the county, beyond which it finds its continuation westward through southern Benton County.

Along the valley of the Wabash there are gravel terraces reaching a height of nearly 100 feet above the stream. The most conspicuous are located below Lafayette, where they receive the name Wea Plain. They are also conspicuous in the vicinity of Battle Ground village, above Lafayette.

Individual wells.—Wells on the terraces of the Wabash near Battle Ground usually obtain no water within 50 feet of the surface, and in some instances are put down to a depth of 60 or 80 feet. Mr. J. M. Hicks's well, in the village of Battle Ground, is 79 feet, entirely through gravel, sand, or other alluvial deposits. Mr. J. P. Clute's well, in the same village, is 60 feet, striking blue till near the bottom. Wells east from Battle Ground, near the mouth of Moots Creek, are not infrequently 75 feet in depth, and are largely through sand and gravel.

On the uplands west from Battle Ground wells usually are obtained at about 20 or 30 feet, but are occasionally deeper. The following sections of wells in that region have been published by Mr. Gorby:[1]

John Livingston's well, 2 miles west of Battle Ground, penetrates—

	Feet.
1. Soil and yellow clay	30
2. Dry sand	20
3. Blue clay	30
4. Cemented gravel	2
5. Loose gravel	13
Total	95

[1] Fifteenth Ann. Rept. Indiana Geol. Survey, pp. 87-95.

James Bryant's well, 3 miles west of Battle Ground, penetrates—

	Feet.
1. Soil and yellow clay	4
2. Blue clay	50
3. Dry sand	20
4. Coarse gravel	2
Total	76

East of the Wabash, in the northern portion of the county, in the vicinity of Buck Creek village, wells are reported by Mr. Gorby to be occasionally 50 to 65 feet in depth. At John Stanfield's a well 65 feet penetrates sand nearly 50 feet before obtaining a coarse water stratum. At Moses Cole's, about 2 miles west of Buck Creek Station, a well penetrates 55 feet of gravel and sand, entering a blue till near the bottom. In Buck Creek village, W. W. C. Brown's well, 50 feet in depth, penetrates till 20 feet, beneath which is a fine yellow sand.

In eastern Tippecanoe County wells are usually obtained at 20 to 40 feet. Mr. Gorby reports an unusually large amount of yellow till in that region, it being frequently 23 to 30 feet in depth.

The gas-well boring at Dayton, in the eastern part of the county, penetrates about 300 feet of drift, of which a large part is thought to be sand.

At Lafayette an artesian well, in the valley of the Wabash, about 55 feet above low-water mark, or 560 feet above tide, penetrates 170 feet of drift and obtains a flow of water from the Lockport limestone at 230 feet. The section of this well published by Mr. Gorby shows variable beds of sand, gravel, and clay to a depth of 30 feet, where a dark-gray clay is entered which extends to the depth of 102 feet. Beneath this there is a series of sand, gravel, and clay beds about 30 feet, below which is a very bowldery bed, 40 feet in thickness, extending to the rock. An analysis of the water from this well appears elsewhere.[1]

The city water supply of Lafayette is obtained from a gravel bed under the Wabash River, about 40 feet below the bed of the stream. The water is found in such abundance at this horizon that the springs which arise from it furnish a considerable portion of the water flowing in the Wabash in dry seasons.

Private wells in Lafayette range in depth from 10 feet up to 60 feet, but are most numerous at 40 to 60 feet. As the city is located on a hillside, with variations of nearly 200 feet in elevation, the wells are obtained from several different horizons. Exposures of the drift are quite extensive in the southern part of the city. They uniformly show a large amount of sand and gravel beneath a comparatively thin sheet of till.

On the gravel terrace in west Lafayette, near Purdue University, which stands about 100 feet above the river, wells are often sunk to the level of the river bed through the sand and gravel of the terrace.

[1] Eighteenth Ann. Rept. U. S. Geol. Survey, Part IV, p. 498.

On the portion of the terrace below Lafayette, known as the Wea Plain, wells are frequently put down to a depth of 100 feet or more, thus reaching the level of the river. In the northeastern portion of the Wea Plain wells encounter a blue till before reaching the level of the river, but throughout much of the terrace the gravel extends below river level. A well on this terrace reported by Mr. Gorby has the following section:

	Feet.
1. Soil	3
2. Fine gravel	40
3. Sand and gravel	32
4. Gravel	40
Total	115

This well is located about 1½ miles south of the river in sec. 30, T. 23, R. 6 W. It is stated that at points nearer the river wells in some instances go to a depth of 125 or 130 feet before obtaining water. At points more remote from the river water is obtained at less depth.

In the southern part of the county wells are quite generally obtained at slight depth, seldom exceeding 30 feet and often but 12 to 20 feet. In this region there is very often a bed of water-bearing gravel or sand at the base of the yellow till, 10 to 15 feet from the surface, which affords sufficient water for wells. In some cases, however, wells are carried into the underlying blue till and obtain water at depths of 30 to 40 or 50 feet.

CARROLL COUNTY.

General statement.—Carroll County is situated in the north-central portion of the State and includes the part of Wabash Valley immediately above Tippecanoe County. Delphi is its county seat. Its area is 370 square miles. The greater part of the county lies on the east side of the Wabash River. On the west there is a narrow wedge of upland occupying the interval between the Wabash and Tippecanoe rivers. There is a continuous ascent from the east bluff of the Wabash southeastward beyond the limits of the county, an altitude of over 800 feet above tide being attained in its southeastern corner. The immediate bluffs of the Wabash are only 675 feet, while the stream is about 125 feet lower.

The surface of the county is either plane or gently undulating, if we except a few sharp drift knolls in the extreme northwest corner. The tributaries of the Wabash have all shallow channels. There is therefore no conspicuous topographic feature within the county except the Wabash Valley, which has a breadth of a mile or more and a depth of 125 to 150 feet. This valley is bordered by gravel terraces similar to those of Tippecanoe County, the highest of which stand fully 100 feet above the level of the river. Lower terraces occur at several heights.

The thickness of the drift varies greatly, there being quite extensive areas in the vicinity of Delphi, where rock is exposed up to a height

of nearly 50 feet above the river. At Monticello, near the northwest corner of the county, the rock floor is found at a level about 100 feet lower than the Wabash. Borings in neighboring portions of Howard and Clinton counties on the southeast show drift 200 to 250 feet or more in thickness, the rock floor being lower than at the outcrops along the Wabash River.

The drift of this county, so far as penetrated in wells, is generally a compact till. Exposures along the streams also are usually mainly till. The wells being shallow over the greater part of the county, the structure of the deeper portion of the drift is not known.

There are very strong springs in the vicinity of Delphi, from which the city water supply is obtained. Their location is about 3 miles northeast of the city, on the farm of George Snyder. The supply is piped to the city and distributed from the standpipe and also by direct pressure.[1]

Individual wells.—Wells are usually obtained at such shallow depths that records of but few of them were obtained. One of the deepest was found at Rockfield, in the northern part of the county, where till to a depth of 57 feet was penetrated and no rock encountered. The dug wells at Rockfield are only 15 to 25 feet in depth. Tubular wells are 50 feet or more.

Along the Wabash terraces, both above and below Delphi, wells are occasionally carried to a depth of 40 feet in gravel and sand; but in the vicinity of Delphi, where rock underlies the terrace at slight depth, they are sometimes found at the base of the gravel 10 to 20 feet. On the narrow strip of upland west of the Wabash records of two wells were obtained, each about 50 feet in depth, one of which was largely through till and the other largely through sand and gravel, though only 40 rods apart.

At Flora a gas-well boring penetrates 136 feet of drift thought to be largely till. There are several flowing wells at this village obtaining water at depths of 12 to 47 feet, the distance to the water-bearing stratum differing in the several wells. The wells are located on low ground along Bachelor's Run, and their head is only about 5 feet above the surface.

CLINTON COUNTY.

General statement.—Clinton County is situated in the north-central portion of the State, south of Carroll and east of Tippecanoe County, with Frankfort as its county seat. It has an area of 400 square miles. This county is an elevated plain, in which the slope is westward and northward from the southeast part. Its highest points are probably 950 feet above tide, while its lowest are about 700 feet. To the traveler, however, the county has the appearance of a nearly level plain, the rate of descent being gradual.

[1] Seventeenth Ann. Rept. Indiana Geol. Survey, p. 172.

The greater elevation of the southeastern portion of the county has been shown by numerous gas-well borings to be due, not to the height of rock surface, but to accumulations of drift, there being about 300 feet of drift in that part of the county.

The surface portion of the drift of this county is a compact till, but gas-well borings show that the deeper portion is largely sand and gravel.

Individual wells.—At Frankfort, the county seat, dug wells are usually obtained at 18 to 25 feet. Tubular wells find a large supply of water at 55 to 65 feet. The wells range in depth from 10 up to 90 feet. In the shallow wells sufficient clay is usually penetrated to insure freedom from surface contamination, though in some cases the water rises so near the surface as to be easily contaminated.

The city water supply of Frankfort is obtained from wells sunk to a depth of about 30 feet below a reservoir which is itself 28 feet in depth. The water fills this reservoir within 3 feet of the surface. Six wells, 8 inches in diameter, are estimated to furnish about 6,000,000 gallons a day. A gas-well boring in the northeast part of Frankfort has the following section:

	Feet.
1. Till	30
2. Quicksand	10 or 15
3. Hard clay and gravel, with flow of water near bottom	25 or 30
4. Gravel and sand, with thin clay beds	197
5. Blue pebbly clay	13
Total	278

A well in the western part of the city did not reach rock at 297 feet. For several miles south and east from Frankfort water is obtained at 15 to 30 feet, being mainly through till, with water-bearing gravel at bottom. North and west from the city the wells are often of greater depth.

At Scircleville a gas-well boring penetrated 296 feet of drift, of which the upper 150 feet is largely till, but the remainder is mainly sand and gravel. Near the east line of the county, about 3 miles east of Scircleville, a gas-well boring enters rock at 260 feet. The drift there is mainly a blue till.

At Kirklin, in the southeast part of the county, a gas-well boring has 252 feet of drift, of which the upper 40 feet is till, but the remainder has alternations of sand and gravel in thin beds, with somewhat thicker sheets of till. The wells in the vicinity of Kirklin obtain a strong supply of water at 40 feet. West from Kirklin wells are often obtained at 16 or 18 feet. Tubular wells are, however, 60 or 70 feet, mainly through till.

At Colfax the deepest wells are 60 or 70 feet, mainly through blue till. Shallower wells are, however, common in that region.

At Mulberry, in the western part of the county, at an elevation 754 feet above tide, a water well at the railway station, 220 feet in depth,

did not reach rock. It is mainly through till. Another well at a sawmill in the same village is 150 feet in depth, mainly blue till.

Near Gittingsville, in the northern part of the county, several flowing wells have been obtained at about 20 feet. They are along a valley in sec. 19, T. 23, R. 1 E. In section 30 of the same township a well at R. O. Young's, 71 feet in depth, penetrates till, with thin beds of gravel and sand.

In the vicinity of Sedalia, in the extreme northern portion of the county, wells are occasionally sunk to a depth of 80 feet through till, but are usually shallower. A well at J. H. Brown's, in sec. 24, T. 23, R. 1 W., 126 feet in depth, penetrates—

	Feet.
1. Till	68
2. Sand, with vegetal deposits and inflammable gas	16
3. Sand	42
4. Gravel, with water at bottom.	
Total	126

In the Fifteenth Report of the Indiana Survey attention is called to the occurrence of many bowlders in the blue till in Stony Prairie, 5 or 6 miles southwest from Frankfort, from the surface down to a depth of 50 feet. The western half of the county is liberally strewn with bowlders, but they seldom extend to such depth as to be troublesome in excavating wells.

HOWARD COUNTY.

General statement.—Howard County is situated in the north-central portion of the State, immediately south of Cass and Miami counties, with Kokomo as its county seat. Its area is 300 square miles. The entire surface of the county is plain or gently undulating, there being few, if any, knolls and ridges rising more than 20 feet above the general level. With the exception of a narrow belt along Wild Cat Creek, west from Kokomo, which is less than 800 feet above tide, and possibly a narrow strip on the north border, the county stands between the 800 and 900 feet contour.

The greater portion of the county has a moderate coating of drift, 75 feet or less. But the southwestern part has a larger amount, there being at Russiaville and neighboring points about 150 feet. Where the drift is of moderate depth it is composed mainly of till, but the deeper portions include much sand and gravel in their lower part. Wells not infrequently find abundance of water at 10 or 20 feet, in beds of gravel between the yellow and blue till, and they rarely penetrate to a greater depth than 40 feet.

Individual wells.—At Kokomo wells are usually obtained at 35 or 40 feet, either in gravel near the base of the drift or in the upper part of the underlying limestone. A few deep wells 100 to 150 feet have been sunk. The city waterworks are supplied from wells 100 feet in depth.

Several gas borings have been made in the vicinity of Kokomo. In some cases the wells have encountered 90 feet of drift, but there is usually a much smaller amount. Some of those in Wild Cat Creek bottom and on the plain south of the creek enter rock at 10 to 20 feet or less. As a rule, these wells are productive of gas. Those to the west of the city in some cases yield no gas, but, instead, a flow of water. In the Indianapolis Sentinel for July 18, 1895, it is stated that one of these wells had been turned to good account by a farmer for irrigation during a season of excessive drought. Where the water contains only a moderate amount of saline matter such wells might be made to return some small share at least of the expense incurred in drilling for the gas.

At the village of Greentown, 8 miles east of Kokomo, wells are usually obtained at 20 to 25 feet in gravel below till. A lower vein of water is obtained at 35 to 45 feet. Gas-well borings at this point show the drift to be about 85 feet in thickness.

At Fairfield, 6 miles southeast of Kokomo, wells are usually obtained at 20 or 30 feet, there being about 20 feet of surface till. The drift in the vicinity of Fairfield is shown by gas borings to range from 25 feet up to fully 75 feet in depth. The well near the railway station has 47 feet of drift, of which the upper 18 or 20 feet is till and the remainder gravel. A well 4 miles west of Fairfield was found to have 165 feet of drift.

A strong flow of fresh water was obtained from the limestone in a well half a mile north of Fairfield at a depth of 110 feet. It is estimated to discharge 5,000 barrels per day. The head is only 6 feet above the surface of the ground, and the well mouth at this point is 25 feet lower than at Fairfield railway station.

At Tampico, about 3 miles northeast of Fairfield, wells are usually obtained at 30 feet. The drift at that point is shown by a gas boring to be 103 feet in depth, of which the upper 25 feet is till; the remainder consists of alternations of sand and till. A well 3 miles northeast of Tampico, bored for gas, has 115 feet of drift. It is reported to have passed through a bed of soil containing leaves at a depth of 103 to 105 feet.

A gas well at Sylvanus Barrett's, in the southeast township of the county, has 98 feet of drift, of which only the upper 10 feet is till, the remainder being gravel, a part of which is cemented.

At Russiaville, in the southwest township of the county, the gas-well boring penetrates 153 feet of drift, as follows:

	Feet.
1. Yellow till	10 to 12
2. Sand with water	3 to 4
3. Blue till	40
4. Sand and gravel, with thin beds of till	95 to 100
Total	153

Water wells in that vicinity are obtained at shallow depths in the sand between till sheets.

TIPTON COUNTY.

General statement.—Tipton County is situated in north-central Indiana, immediately south of Howard County, with Tipton as its county seat. Its area is 260 square miles. The surface of this county, like that of Howard, is gently undulating, and there is a thicker deposit of drift in its western than in its eastern portion. The western portion is also correspondingly higher. In the southwestern part of the county the altitude exceeds 900 feet, while in the northeastern it is little more than 800 feet. The drift in the southwestern part is 250 to 300 feet in depth, while in the northeastern it is 75 to 100 feet. The surface portion of the drift is generally a compact till, but the deeper portion contains large amounts of sand and gravel.

Individual wells.—At Sharpsville, on the north border of the county, the gas-well borings pass through about 70 feet of drift, mainly till. Water wells are obtained at 20 or 25 feet or less, in thin beds of sand or gravel associated with the till.

At the village of Windfall, in the northeast part of the county, the drift at a gas boring is 72 feet. There are, however, thin beds of sand and gravel associated with the till, which afford water for the wells.

On the east border of the county, in the vicinity of Elwood, the drift ranges from 40 feet up to more than 100 feet in the several gas wells which have been sunk. It is mainly a blue till, but with the till there are beds of sand and gravel furnishing water at moderate depths.

In the vicinity of Hobbs Station, and southeastward to the southeast corner of the county, gas wells usually enter rock at about 70 or 80 feet, and the greater portion of the drift is till.

At Tipton, near the center of the county, the gas wells show 140 to 200 feet of drift, the greatest depth being found on the bank of Cicero Creek, in the east part of the city. The dug wells are often obtained at shallow depths, 12 to 20 feet, and it is thought they are liable to surface contamination, as the drift is of a porous, gravelly constitution. Better wells are found at 50 to 100 feet, after penetrating a sheet of till. Fresh water may be obtained from the limestone, also at several horizons down to about 400 feet, below which depth it is liable to become brackish. The city water supply is derived from near the top of the limestone.

At Kempton, in the western part of the county, water is usually obtained at about 35 feet, in the gravel between sheets of till. Several gas wells have been sunk in the vicinity of Kempton, which show the drift to be 240 to 300 feet in thickness. One of these borings, in the east part of the village, penetrates the following drift series:

	Feet.
1. Yellow till	10
2. Sand and till, each in beds a few feet thick	165
3. Gravel	65
4. Sand	17
Total	257

Another well in the village with 305 feet of drift penetrates—

	Feet.
1. Till, with thin sand beds	200
2. Sand and gravel	80
3. Hard brown till	25
Total	305

A gas well half a mile east of Kempton has 243 feet of drift, consisting mainly of till, but having thin beds of sand and gravel.

At the village of Atlanta a gas-well boring penetrates about 300 feet of drift. Several gas-well borings in the southwest part of the county also penetrate drift 250 to 300 feet.

The following drift section appears in a gas boring near the center of the county, 3 miles east of Tipton:

	Feet.
1. Till, yellow and blue	38
2. Gravel	5
3. Blue till	45
4. Gravel	15
Total	103

A gas well in sec. 10, T. 21, R. 5 E., penetrates 130 feet of drift, as follows:

	Feet.
1. Yellow till	10
2. Gravel	20
3. Blue till	80
4. Gravel	20
Total	130

GRANT COUNTY.

General statement.—Grant County is situated in the north-central part of the State, with Marion as its county seat, and has an area of 420 square miles. It is traversed nearly centrally from southeast to northwest by the Mississinewa River. Along the east border of this stream is the Mississinewa moraine, having a breadth of about 5 miles. Aside from this moraine the surface of the county is a gently undulating plain. The moraine itself has gentle swells and sags and is not strikingly in contrast with the plains. Its relief, however, being 50 feet or more, makes it a noticeable feature.

On the portion of the county west from the Mississinewa River the drift is usually thin, it being often but 20 feet or even less in depth. This district, however, appears to be traversed by deeply filled valleys in which the drift has a thickness of 150 to 160 feet or more. In the northeastern part of the county the drift deposits seldom fall below 100 feet, and probably average nearly 150 feet. Throughout the county the surface portion of the drift is generally a compact till. In places where the drift is thick the deeper portions are often made up largely of sand and gravel.

Individual wells.—At the city of Marion the waterworks are supplied from two classes of wells—first, drift wells 70 feet in depth; second, wells in limestone 240 feet in depth. From both classes of wells the water rises nearly to the surface. A well 8 inches in diameter is estimated to yield nearly 4,000 barrels per day. The drift at Marion ranges from about 30 feet in the north part of the city to 150 feet or more in the south part. The upper portion generally is till to a depth of 30 to 45 feet, the remainder largely sand and gravel.

At Jonesboro, about 6 miles above Marion, on the Mississinewa River, wells are obtained in gravel below till at depths of 10 to 45 feet. The gas-well boring in the village shows the drift to be 162 feet.

At Upland, in the eastern part of the county, wells are usually obtained at about 30 feet, in a bed of gravel between sheets of till. A few wells are sunk into the underlying rock and obtain water at about 150 feet. The waterworks supply is from these rock wells.

At Van Buren the gas well penetrates 92 feet of drift, largely till. Wells in the vicinity of that village are obtained at 20 or 30 feet.

A gas boring in the northwestern part of the county penetrates 182 feet of drift, which is reported to be mainly sand and gravel.

In the southwestern portion of the county, although the drift is thin, wells are usually obtained without entering the rock, there being generally a water-bearing gravel at the base of the drift. Gas-well borings in this part of the county show the drift to have the following thicknesses at the principal villages: At Switzer, 28 feet; at Swayzee, 22 feet; at Simms, 45 feet; at Point Isabel, 22 feet; at Fairmount, 5 to 35 feet, the thickness varying in different wells. At Fairmount water wells are often drilled into the rock to a depth of about 30 feet. The waterworks supply is from such wells.

BLACKFORD COUNTY.

General statement.—Blackford County is situated somewhat north of the middle of the eastern portion of the State, and is one of the smallest counties, having an area of 170 square miles. Its county seat is Hartford City. The Mississinewa moraine traverses the southern townships of the county from west to east, and occupies about 75 square miles. The remainder of the county is a plain. With the exception of a narrow belt in the northeastern part, along the Salamonie River, the drift of this county is about like that of northeastern Grant County—100 to 150 feet or more in thickness. In the northeast corner the thickness is but 20 or 30 feet, or even less. The drift is composed mainly of a compact till, though beds of sand and gravel are sufficiently numerous to supply water for most of the wells at moderate depths.

Individual wells.—At Montpelier, in the northeastern part of the county, wells are in some cases drilled into the limestone, though usually obtaining water at the base of the drift at depths of 15 to 30 feet.

At Mill Grove, in the eastern part of the county, a gas-well boring penetrates 143 feet of drift, mainly till. Water wells are usually obtained at moderate depths, seldom more than 40 feet. In a few instances, however, they reach a depth of fully 100 feet in that part of the county.

At Hartford City the several gas borings show the drift to range in depth from 80 feet up to 150 feet or more. It is composed of till, interrupted by occasional thin beds of sand. The waterworks supply is from wells drilled into the underlying limestone to a depth of about 250 feet. A well at one of the hotels in Hartford City enters rock at 112 feet. The upper 80 feet is a nearly solid bed of till, below which is 32 feet of sand and gravel. A well 1 mile northwest of Hartford City, in section 10, has 177 feet of drift, of which the upper 100 feet is till and the remainder largely sand. One well in the southeast part of Hartford City enters rock at about 80 feet after penetrating 60 feet of till and about 20 feet of sand.

JAY COUNTY.

General statement.—Jay County is situated on the eastern border of the State, somewhat north of the middle, with the county seat at Portland. Its area is 396 square miles. This county is traversed from west to east by two morainic belts, the Mississinewa and the Salamonie. The Mississinewa moraine is confined mainly to the southern tier of townships and has a breadth of about 5 miles. The Salamonie moraine is situated mainly in the northern tier of townships, but enters the northern portion of the middle tier near the State line. Its breadth is 3 to 5 miles. The remainder of the county has a nearly plane surface, sloping gently toward the north. With the exception of a few sharp knolls on the Salamonie moraine near Camden (Pennville post-office), in the northwest part of the county, the moraines have gentle swells and sags, which give them but little contrast with the gently undulating plains. They present, however, a nearly continuous ridge with relief of 30 to 50 feet or more above the bordering plains. The altitude of the southern portion of the county exceeds 1,000 feet. The northern border of the county falls below 900 feet.

The drift is composed mainly of a sheet of compact till, and its thickness probably averages about 100 feet. The rock is rarely struck at less than 50 feet, and at Geneva, near the north border of the county, a gas-well boring shows 350 feet of drift.

Individual wells.—Along the north border of the county, near the State line, rock is found at 10 to 20 feet, and wells are often sunk into it to slight depths. The thin drift, however, occupies but a few square miles. At Bryant, near the middle of the north line of the county, the drift was found to be 112 feet in thickness.

About 6 miles west of Bryant, in secs. 19 and 30, T. 24, R. 13 E., wells are difficult to obtain, the moraine at that point being composed

of till to a depth of 125 feet or more. One well has a depth of 125 feet, another 140 feet, and another 155 feet, none of which enter rock. About a mile west of these wells rock is struck at 130 feet in a well in section 13, Penn Township.

At Pennville, in southern Penn Township, on the Salamonie River, rock is struck at about 40 feet in several gas borings.

At Portland, the county seat, wells are often obtained at 14 to 30 feet in gravel, but more frequently they are drilled into limestone, which is entered at 30 to 60 feet in the vicinity of this town. A few wells have a depth of 150 feet. The waterworks supply is from wells drilled into the limestone. It is thought that the shallow wells are protected from contamination by a bed of clay which overlies the water-bearing gravel.

Immediately east of Portland wells are obtained in sand between yellow and blue tills at 12 to 20 feet; the blue till is struck at 15 to 30 feet, and extends to the underlying rock at 45 to 50 feet.

A well in section 18, Noble Township, 5 miles east of Portland, enters rock at 83 feet; one in section 17 enters rock at 160 feet, and one in section 7 enters rock at 57 feet. They are all situated near the south border of the Salamonie moraine and are mainly through till.

Near Bellefontaine, in the east part of the county, wells enter rock at 80 to 135 feet and are mainly through till.

At Como, 6 miles southwest from Portland, the drift is 80 feet, and at Red Key 73 feet, mainly till at both places.

At Dunkirk, in the southwestern part of the county, the best wells are obtained near the top of the limestone at depths of 65 to 100 feet. The waterworks are supplied from wells of this class. Shallower wells afford only a small amount of water.

Along the Mississinewa moraine, in the southern part of the county, farmers not infrequently have sunk wells to a depth of 50 to 75 feet or more before obtaining an adequate supply of water. This moraine appears to afford but little water at shallow depths.[1]

[1] The size of a single paper in this series being limited by law to 100 pages, the remainder of this paper—the portion relating to the southern part of the State—will be published as Water-Supply Paper No. 26 (in press).

INDEX.

	Page.
Adams County, description of wells in	51–52
Ainsworth, description of wells near	14
Albion, description of wells at	32, 34
Allen County, description of wells in	48–51
Ambia, description of wells near	64, 66
Amboy, description of wells at	58
Andrews, description of wells near	54–55
Angola, description of wells near	28–29
Atlanta, description of wells at	76
Atwood, description of wells at	36
Auburn, description of wells near	30
Avilla, description of wells near	33
Battle Ground, description of wells near	68–69
Bellefontaine, description of wells near	79
Benton County, description of wells in	61–66
Blackford County, description of wells in	77–78
Blair, description of well at	16
Bluffton, description of wells at	53
Boone Grove, description of wells at	18
Boswell, description of well near	64, 65
Bremen, description of wells near	38
Brimfield, description of wells near	34
Brooke, description of wells near	43
Bryant, description of wells near	78–79
Buck Creek, description of wells near	69
Bunker Hill, description of wells near	58
Burkett, description of wells near	37
Butler, description of wells near	30
Carroll County, description of wells in	70–71
Cass County, description of wells in	59
Chalmers, description of wells near	61
Chamberlin, T. C., cited	11
Chesterton, description of wells near	16
Churubusco, description of wells at	48
Claypool, description of wells near	37
Clinton County, description of wells in	71–73
Colfax, description of wells at	72
Collins, description of wells at	48
Columbia City, description of wells at	48
Crown Point, description of wells near	14
Dayton, description of well at	69
Decatur, description of wells at	51
Dekalb County, description of wells in	29–31
Delphi, description of wells near	71
Denver, description of well at	58
Dryer, C. R., cited	25, 26, 27, 28
Dunkirk, description of wells at	79
Earl Park, description of wells near	62
Elkhart, description of wells at	24
Elkhart County, description of wells in	23–25
Elwood, description of wells at	75
Erie ice lobe, description of	11
Etna Green, description of wells at	36
Fairfield, description of wells near	74
Fairmount, description of wells at	77
Flora, description of wells near	71
Fort Wayne, description of wells at	49
Fowler, description of wells near	63
Frankfort, description of wells near	72
Fulton County, description of wells in	46–47
Furnessville, description of well at	16
Galveston, description of wells at	59
Garrett, description of wells at	31
Geneva, description of wells at	52
Gibson, description of wells at	14
Gittingsville, description of wells near	73
Glacial conditions of Indiana	9–13
Goshen, description of wells at	24
Grant County, description of wells in	76–77
Greentown, description of wells at	74
Hageman, description of wells at	16
Hammond, description of wells at	14
Hartford City, description of wells near	78
Hawville, description of wells near	34
Hebron, description of wells at	18
Hessville, description of wells at	14
Hobart, description of wells near	14
Hobbs Station, description of wells at	75
Howard County, description of wells in	73–74
Hudson, description of wells near	29
Huntington, description of wells at	54
Huntington County, description of wells in	54–55
Illinoian drift sheet, description of	10
Inwood, description of wells at	38
Iowan drift sheet, description of	10
Jackson Center, description of wells near	18
Jasper County, description of wells in	44–45
Jay County, description of wells in	78–79
Jonesboro, description of wells at	77
Kempton, description of wells near	75–76
Kendallville, description of wells near	32–33
Kentland, description of wells near	41–42, 43
Kewanna, description of wells at	47
Kirklin, description of wells near	72
Knox, description of wells at	39–40
Kokomo, description of wells near	73–74
Kosciusko, description of wells at	36
Kosciusko County, description of wells in	35–37
Kouts Station, description of wells at	18
Lacrosse, description of wells near	21
Lafayette, description of wells near	69–70
Lafontaine, description of wells at	56
Lagrange, description of wells near	25–26
Lagrange County, description of wells in	25–27
Lagro, description of wells near	57

	Page.
Lake, description of wells at	14
Lake County, description of wells in	13–14
Lake Maxinkuckee, description of wells near	38–39
Laketon, description of wells at	56
Laporte County, description of wells in	18–21
Ligonier, description of wells at	35
Liverpool, description of wells at	14
Loess defined	10
Logansport, description of wells near	59
Marion, description of wells at	77
Marshall County, description of wells in	37–39
Maxinkuckee moraine, description of	11
Medaryville, description of wells at	46
Mentone, description of wells near	37
Metz, description of wells near	29
Miami County, description of wells in	57–58
Michigan City, description of wells near	19–20
Milford, description of wells at	36
Mill Grove, description of wells at	78
Miller Station, description of well near	14
Mishawaka, description of wells at	22
Monon, description of wells at	60
Monticello, description of wells at	60
Montpelier, description of wells at	77
Morocco, description of wells at	43
Mount Ayer, description of wells at	43
Mulberry, description of wells at	72–73
New Haven, description of wells near	50
New Lancaster, description of wells near	54
New Madison, description of wells near	57
New Paris, description of wells near	24–25
Newell, F. H., letter of transmittal by	7
Newton County, description of wells in	40–43
Noble County, description of wells in	31–35
Noblesville, description of wells near	34
North Galveston, description of wells near	36
North Judson, description of wells at	40
North Liberty, description of wells near	23
North Manchester, description of wells near	55–56
Oswego, description of wells near	36
Otterbein, description of wells near	64–65
Oxford, description of wells near	65–66
Pennville, description of wells at	79
Peru, description of wells near	58
Pierceton, description of wells near	36
Pleasant Mills, description of wells at	52
Plymouth, description of wells near	38
Porter County, description of wells in	15–18
Portland, description of wells near	79
Pulaski County, description of wells in	46
Remington, description of wells at	45
Rensselaer, description of wells near	45
Reynolds, description of wells near	60–61
Roanoke, description of wells near	54
Rochester, description of wells at	47
Rockfield, description of wells at	71
Rome City, description of wells near	34
Royal Center, description of wells at	59
Russiaville, description of wells near	74
Saginaw ice lobe, description of	11
St. John, description of wells near	14
St. Joseph, description of wells near	31
St. Joseph County, description of wells in	21–23
Scircleville, description of wells near	72
Sedalia, description of wells near	73
Sharpsville, description of wells at	75
Somerset, description of wells near	56
South Bend, description of wells near	22, 23
South Milford, description of well near	27
Spencerville, description of wells near	31, 50
Starke County, description of wells in	39–40
Steuben County, description of wells in	27–29
Sugar Grove, description of well at	63
Surrey, description of wells near	44
Talbot, description of well near	64, 65
Tampico, description of wells at	74
Teegarden, description of wells near	38
Templeton, description of wells near	65, 66
Till defined	12
Tippecanoe County, description of wells in	67–70
Tipton, description of wells at	75, 76
Tipton County, description of wells in	75–76
Tolleston, description of wells at	1
Uniondale, description of wells near	53
Upland, description of wells at	77
Valentine, description of well near	26
Valparaiso, description of wells near	17–18
Valparaiso moraine, description of	11
Van Buren, description of wells at	77
Wabash, description of wells at	56
Wabash County, description of wells in	55–57
Walkerton, description of wells near	23
Walton, description of wells at	59
Warren, description of wells near	55
Warren County, description of wells in	66–67
Warsaw, description of wells near	36–37
Waterloo, description of well at	30
Wells County, description of wells in	52–53
West Lebanon, description of wells near	67
Wheeler, description of wells near	17
White County, description of wells in	60–61
Whiting, description of wells at	14
Whitley County, description of wells in	47–48
Williamsport, description of wells near	66–67
Winamac, description of wells at	46
Windfall, description of wells at	75
Wisconsin drift sheet, description of	10
Wolcottville, description of well near	27
Xenia, description of wells at	58

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DEPARTMENT OF THE INTERIOR

WATER-SUPPLY

AND

IRRIGATION PAPERS

OF THE

UNITED STATES GEOLOGICAL SURVEY

No. 22

SEWAGE IRRIGATION, PART II.—RAFTER

WASHINGTON
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UNITED STATES GEOLOGICAL SURVEY

CHARLES D. WALCOTT, DIRECTOR

SEWAGE IRRIGATION

PART II

BY

GEORGE W. RAFTER

WASHINGTON

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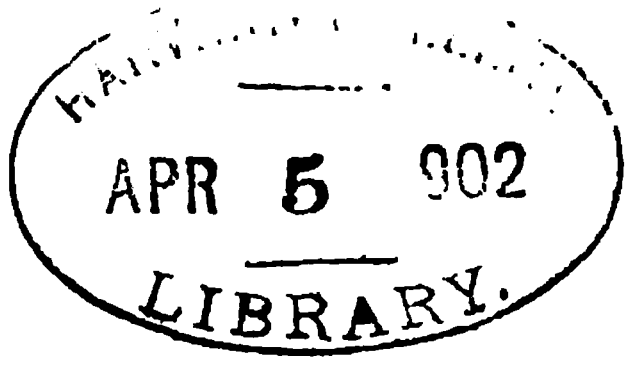

Chas Moore

CONTENTS.

	Page.
Letter of transmittal	9
Résumé of Water-Supply and Irrigation Paper No. 3	11
Climatic and geographic distribution of sewage-disposal works	11
Origin of sewage irrigation	13
Comparison of English and American sewage	13
Pollution of rivers	15
Sewage purification at manufacturing establishments	22
Massachusetts experiments on the purification of factory wastes	27
Paper-mill wastes	27
Wool-scouring wastes	27
Tannery wastes	28
Dyestuffs	29
Special experiments	30
Mechanical analyses of sands	31
Size of grain	31
Air and water capacities of sand	33
Limitation of size of dose	33
Purification obtained by intermittent filtration	34
Summary of Massachusetts experiments	34
Value of commercial fertilizers	35
Necessity of purification of sewage at towns on the Great Lakes	36
Effect of sewage on lake waters	37
Danger of winter typhoid	38
American sewage-disposal plants	41
Maine	41
Augusta, State Insane Asylum	41
New Hampshire	41
Concord, State Insane Asylum	41
Rockingham County Poor Farm	42
Massachusetts	42
Amherst	42
Brockton	42
Gardner	45
Greenfield	46
Lenox	46
Marlboro	46
Concord, Massachusetts Reformatory	48
Medfield	48
Mystic Valley	48
Natick	50
Norfolk County Jail	51
North Brookfield	51
Pegan Brook	52
Waltham, School for the Feeble-minded	52
Sherborn Prison	52

American sewage-disposal plants—Continued.
Massachusetts—Continued. Page.
South Framingham 52
Wellesley College 53
Westboro 53
Worcester 53
Worcester Insane Hospital 55
Plants projected in Massachusetts 56
Rhode Island 57
Central Falls 57
Pawtucket 58
Cranston, State institutions 59
Providence 59
Woonsocket 59
Connecticut 59
Bristol 59
Danbury 60
Lake Wauremaug 60
Litchfield 60
Manchester 60
Meriden 61
Waterbury 62
New York 62
Brewsters 62
Brooklyn, twenty-sixth ward 62
Chautauqua Assembly 63
Far Rockaway 64
New Rochelle 64
Hemlock Lake 64
Bath, Soldiers' and Sailors' Home 65
Batavia, State Institution for the Blind 65
Vassar College 65
Plants projected in New York 67
New Jersey 69
Atlantic City 69
East Orange 70
Essex Fells 70
Freehold 70
Lawrenceville School 70
Long Branch 70
Morris Plains Asylum 70
Plainfield 71
Princeton College 71
Summit 71
Westfield 72
Pennsylvania 72
Altoona 72
Norristown, State Hospital for the Insane 73
Reading 73
Wayne 74
West Virginia 74
Weston, State Insane Hospital 74
Texas 74
Paris 74
San Antonio 75
Temple 75

American sewage-disposal plants—Continued. Page.
Ohio 75
Alliance 75
Canton 75
Fostoria 76
Oberlin 76
Michigan 77
Wayne County poor farm 77
St. Johns 77
Illinois 77
Pullman 77
World's Fair 79
Wisconsin 79
Menominee Valley 79
Minnesota 79
Rochester Hospital for the Insane 79
Nebraska 80
Hastings 80
Colorado 80
Colorado Springs 80
Leadville 80
Trinidad 81
Montana 81
Helena 81
Utah 81
Salt Lake City 81
Arizona 82
Phœnix 82
California 82
Fresno 82
Los Angeles 82
Pasadena 84
Redding 85
San Luis Obispo 85
Santa Rosa 85
Stockton 85
Dominion of Canada 85
Berlin 85
Hamilton 88
London 88
London Hospital 88
Ontario Agricultural College 89
Waterloo 89
Publications relating to sewage utilization and disposal 89
Index 99

ILLUSTRATIONS.

Page.

PLATE I. Brockton, Massachusetts, filtration fields; *A*, Turnips and sweet corn; *B*, Pease, sweet corn, and beans 42

II. South Framingham, Massachusetts, sewage farm; *A*, Sewage inlet to filter; *B*, Portion of cabbage field 52

III. Works at Worcester, Massachusetts; *A*, General view of precipitation tanks; *B*, Another view of precipitation tanks..... 54

IV. Filter areas as ridged for winter service at Pawtucket, Rhode Island. 58

V. Sewage disposal at Plainfield, New Jersey; *A*, Main carrier as seen from screen tank (before erection of building); *B*, Distributing channel in bed No. 1..... 70

VI. Sewage irrigation at Salt Lake City, Utah; *A*, Main ditch, outlet gate, and field of corn; *B*, Lateral ditch and method of irrigating corn. 80

VII. *A*, Sewage irrigation at Phœnix, Arizona; *B*, Sidehill irrigation at Wayne, Pennsylvania 82

FIG. 1.—Mechanical composition of materials available for sewage filtration .. 32

2.—Air and water capacities of sewage filter materials 32

3.—Limitation of size of single dose by air and water capacities..... 33

4.—Plan of filter areas at Pawtucket, Rhode Island..... 58

LETTER OF TRANSMITTAL.

DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
DIVISION OF HYDROGRAPHY,
Washington, October 25, 1898.

SIR: I have the honor to transmit herewith a manuscript entitled Sewage Irrigation, Part II, prepared in October, 1897, by Mr. George W. Rafter, of Rochester, New York. This paper consists in part of material furnished for Water-Supply and Irrigation Paper No. 3, on Sewage Irrigation. In the printing of that paper it was found that the limit of 100 pages set by law would be exceeded in spite of considerable condensation in the form of statement. The original manuscript was therefore divided into two parts, the first, relating to the general subject and giving the practice abroad, having already appeared as Paper No. 3. The present manuscript, which has been considerably extended by Mr. Rafter, is devoted mainly to the discussion of data obtained in this country and in Canada, and of all the plants erected and operated, together with brief notes on the projected plants. There is included an appendix containing a list of publications relating to the subject.

Very respectfully,

F. H. NEWELL,
Hydrographer in Charge.

Hon. CHARLES D. WALCOTT,
Director United States Geological Survey.

SEWAGE IRRIGATION, PART II.

By GEORGE W. RAFTER.

RÉSUMÉ OF WATER-SUPPLY AND IRRIGATION PAPER NO. 3.

In a previous publication on sewage irrigation[1] we discussed the general principles governing the utilization of sewage in agriculture, as well as the relations of such utilization to the public health. It was shown, also, how the gradually increasing pollution of streams first led in England and other manufacturing countries, to a demand for sewage purification, and the probable value of sewage in agriculture was indicated.

In that paper the various methods of sewage disposal in common use were discussed, with special reference to the modern views about nitrification. Descriptions of methods of applying sewage were given with information as to the best crops for sewage farming, the proper quantity of sewage to be applied, limiting temperatures, cost of labor on sewage farms, sanitary condition of such farms, and a number of other important subjects which it is necessary that one should understand before embarking in sewage-utilization investments. Brief descriptions were also given of a number of the principal sewage farms in England, of the sewage farms of the city of Berlin, Germany, and of sewage utilization in France on the Plain of Gennevilliers.

In the present paper it is proposed to give additional data relating to stream pollution and sewage purification, together with a brief account, so far as it has been possible to obtain the information, of every sewage-disposal plant in the United States and the Dominion of Canada, whether now in use or abandoned, that has actually been built, or that has had plans prepared for its construction.

CLIMATIC AND GEOGRAPHIC DISTRIBUTION OF SEWAGE-DISPOSAL WORKS.

As regards rainfall, the United States divides naturally into three regions—the humid, subhumid, and arid. The humid region includes all of the country east of the Mississippi River, together with the States of Iowa, Missouri, Arkansas, and Louisiana west of that river.

[1] Water-Supply and Irrigation Paper No. 3, 1897, 100 pp., 4 pls.

It also includes portions of North Dakota, South Dakota, Nebraska, Kansas, Indian Territory, and Texas. The subhumid region may be taken to include the remainder of North Dakota, South Dakota, Nebraska, Kansas, Indian Territory, and Texas. The arid region embraces Arizona, California, Colorado, Idaho, Montana, Nevada, New Mexico, Oregon, Utah, Washington, and Wyoming, although limited areas in several of these States and Territories may be classed as humid.

The great lack of water in the subhumid and arid regions would naturally indicate a relatively large development of sewage irrigation in those portions of the United States. As a matter of fact, however, other conditions than mere shortage of water have controlled—for instance, the degree of advancement of the towns themselves—and we accordingly find, on the whole, more sewage irrigation and general purification in the humid East than in the subhumid and arid West. The Western towns are, nevertheless, advancing rapidly, and we may expect changes in the figures in the near future.

The following paragraph gives the approximate statistics of sewage purification in the United States to-day:

In the humid region there are sewage-purification plants in operation, actually building, projected, or built and abandoned, distributed by States as follows: Maine, 1; New Hampshire, 2; Massachusetts, 32; Rhode Island, 5; Connecticut, 7; New York, 33; New Jersey, 11; Pennsylvania, 5; Maryland, 1; West Virginia, 1; Louisiana, 1; Texas, 3; Ohio, 11; Michigan, 2; Illinois, 2; Wisconsin, 2;[1] Minnesota, 1; a total of 120 for the humid region. In the subhumid there is 1 in Nebraska. In the arid region Arizona has 1; Colorado, 4; California, 8; Montana, 1; Utah, 1; Wyoming, 1, or a total of 16. There are also six plants in the humid portion of the Dominion of Canada.[2]

The foregoing figures indicate a total for the United States and Canada of 143. About 120 of these plants have been either built or projected in the last ten or twelve years. This total includes, so far as can be learned, all the purification plants of every kind, whether irrigation, intermittent filtration, or combined chemical-purification and filtration and irrigation plants, either actually in operation now or formally projected and in such a state of advancement as probably to be carried out in a few years.

The intermittent-filtration plants are properly included in a paper on sewage irrigation, because the filtration areas either now are used for raising crops or are likely in the end to be so used. As to the propriety of including the chemical-purification plants, it may be pointed out that this system of purification has been adopted in several towns before all the controlling conditions were taken into account. In one case an

[1] Aside from three plants for purifying manufacturing wastes, etc., there are only two sewage-disposal works in Wisconsin.

[2] The foregoing statistics of the distribution of sewage-disposal works were prepared in September, 1897. At the present date (February, 1899) there are a few additions.

eastern town has adopted chemical purification and operated the plant at large expense, in spite of the existence of ideal conditions for irrigation and filtration in the immediate vicinity. It is probable, therefore, that, as soon as the advantages of irrigation and filtration are more fully known, a number of the chemical-purification plants will be changed to either irrigation or filtration, or, without a complete change of plant, the effluents from chemical-purification works will be further treated by either irrigation or filtration. This proposition is especially true of a number of chemical plants in the State of New York, where the capitalized cost of chemical treatment will be considerably in excess of that of intermittent filtration, even though sand of the proper quality were transported some distance and high-grade filtration areas constructed. It is in this view of the case that the statistics of chemical-purification plants are herein included. There are also a number of cities and villages in the Eastern part of the United States where crude sewage is discharged into ponds, lakes, and running streams, which either now are or are likely in the future to be the source of public water supplies. In the end the sewage of all such will require purification. In many cases proper land areas can be had in the immediate vicinity; hence we find an additional reason why a complete exhibit of the whole subject should be made at this time. All town authorities need to understand that, with other conditions equal, the capitalized cost of the land-purification processes is ordinarily less than that of the chemical. Farmers in the vicinities of towns need also to understand this, as well as the benefits to themselves to be derived from the utilization of sewage in agriculture.

ORIGIN OF SEWAGE IRRIGATION.

The growth in England of great manufacturing industries and the consequent pollution of the streams of that country at the beginning of the present century forced the English cities to consider the necessity for sewage purification at an earlier date than elsewhere. Sewage irrigation as a branch of applied science may therefore be said to have originated in England. At the present time a more general use of sewage purification may be found in that country than elsewhere, although, as we have seen in Water-Supply and Irrigation Paper No. 3, the Germans and the French have now extensive sewage-purification plants of a high order of excellence. Nevertheless it is true that a large proportion of the data of sewage disposal, as it exists to-day, must necessarily be drawn from English practice.

COMPARISON OF ENGLISH AND AMERICAN SEWAGE.

First of all, it is necessary that we establish in some way a measure of the relation which average English sewage bears to American. The great difficulty in making comparisons is the fact that the English

chemists, following the lead of Dr. Frankland, have mostly used the combustion process in their sewage analyses, while in the United States the Wanklyn albuminoid-ammonia process has been almost exclusively used.

By way of explaining the terms used, it may be pointed out that free ammonia as determined by the Wanklyn process represents that portion of the nitrogenous matter present which has already, at the time of analysis, passed into a state of decay; whereas the albuminoid ammonia represents the nitrogenous matter which has not, at the time of analysis, undergone decay. These are the two main determinations of the Wanklyn process.

In the combustion process Dr. Frankland attained much greater refinement than is possible with the albuminoid-ammonia process of Wanklyn, and the only reason why the combustion process has not been universally adopted is because of the difficulty of working it. By its use we determine not only the different states of the nitrogen, but that portion of the organic matter present which is carbonaceous in its character, or, technically, the organic carbon. The organic nitrogen of the process is that portion of the nitrogenous matter due to living substances, and corresponds in a general way with the albuminoid ammonia of Wanklyn. The ammonia represents dead and usually animal matter, and is, in the opinion of Dr. Frankland, the chief index of recent sewage contamination.

There are four states of the nitrogen as found in contaminated water—ammonia, free ammonia, nitrite, and nitrate. The nitrates represent the final fixation of the ammonia by combination with a mineral base, and hence a state of innocuousness. By a comparison of these various states Dr. Frankland arrives at the previous sewage contamination, which is one of the most interesting determinations of his system.[1]

If we refer to the various reports of the Rivers Pollution Commission, the Royal Commission on Metropolitan Sewage Discharge, or the Royal Commission on Metropolitan Water Supply, or to the various reports of the English local government boards, we find the analyses usually given in terms of the combustion process, in which organic carbon, organic nitrogen, ammonia, and total combined nitrogen may be considered the chief controlling constituents. Referring to a table in the first report of the Rivers Pollution Commission, on pages 28 and 29, we find that in English water-closet towns the total solids in solution in the sewage amount, on an average, to 72.2 parts per 100,000; the organic carbon to 4.696 parts per 100,000; the organic nitrogen to 2.205 parts per 100,000; the ammonia to 6.703 parts per 100,000; the total combined nitrogen to 7.728 parts per 100,000; and the chlorine to 10.66 parts per 100,000. Of the suspended matters the minerals

[1] For a definition of these several elements of the combustion process in detail the reader is referred to Recent advances in water analyses, etc., by the author, in American Monthly Microscopical Journal, May, 1893, p. 127.

amounted to 24.18 parts per 100,000, and the organic to 20.50 parts per 100,000, giving a total of 44.69 parts. If we bear in mind that free ammonia, albuminoid ammonia, and organic nitrogen refer to the same things, and also that the organic nitrogen is usually about double the albuminoid, we may still make comparisons which are close enough for the ordinary purposes of agriculturists.

Comparing several series of analyses, both American and English, it becomes apparent that ordinary town sewage in England is usually considerably more concentrated than that of the American towns. It is very important to bear this in mind in applying English data to American conditions. The elaborate experiments conducted by the Massachusetts State board of health at Lawrence, which have been reported from year to year in the annual reports of that board from 1888 to the present time, indicate that there is a relation between the purifying capacity of different filtrating materials and the amount of impurity which can be removed from sewage of a given strength. This point is strongly brought out by the experiments. It follows, then, that if we prepare special areas for sewage purification in accordance with the indications of the Massachusetts experiments, we may expect to apply sowewhat larger volumes of average American dilute town sewage per unit of area than has usually been found expedient in English practice. If, therefore, we use English data without reference to the quality of the soil to which the sewage is to be applied, or of the sewage itself, we shall be likely to arrive at more or less erroneous conclusions.

As a summation of this part of our discussion, we may say that the chief object of sewage purification is to rid the sewage of a thousandth part, more or less, of the organic matter which it contains, and that all of the appliances for sewage purification and utilization may be considered as directed toward this one point.

POLLUTION OF RIVERS.

This division of the general subject has been discussed in Water-Supply and Irrigation Paper No. 3 under the general head of "Stream pollution." The following additional information is herewith presented by way of extending somewhat the discussion there given:[1]

As an exceedingly marked case of river pollution, we may refer to the report of the Passaic Valley Sewerage Commission, authorized by an act of the New Jersey legislature approved February 26, 1896. The report of the commission appointed under the terms of this act was issued in February, 1897, and therefore may be cited as one of the most recent extended studies on stream pollution to be had.

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[1] For a more extended discussion of river-pollution questions the reader is referred to River pollution in the United States, by Charles C. Brown, a paper read before the Engineers' Club of St. Louis, June 18, 1890, and published in the Journal of the Association of Engineering Societies for October, 1890, Vol. X, No. 10, p. 475, and to Sewage Disposal in the United States, Chapter III. The two works give, with the present discussion, the bulk of the published information as to river pollution in the United States.

At its head waters, among the hills of Somerset County, New Jersey, the Passaic River is a pure, clear running stream. The same is true of its principal upper tributaries, the Rockaway and Pompton rivers; and while there is some manufacturing in the upper valleys, the river continues bright and inviting until it reaches Little Falls, at which place it receives the drainage from several residences and factories. After passing Paterson, 3 or 4 miles below Little Falls, its character completely changes, and from that point to Newark Bay, as stated by the Passaic commission, "its pollution is enormous, constant, and increasing yearly." About 436,000 persons now inhabit the district drained by the lower river, furnishing fully 70,000,000 gallons of sewage a day. So great is the extent of the pollution below Paterson that fish life, except a few hardy kinds, has entirely disappeared. The sewage-laden mud shores give out foul odors. Steam users report that the acids of the sewage-laden water have so affected their boilers as to make its use unadvisable. Formerly thousands frequented the river for pleasure purposes, but this is no longer a practice.[1]

In 1880 the population of the towns dischaging sewage into the lower Passaic River was 246,503, and in 1895 it was 436,423.

The ratio of increase in population of the lower Passaic district from 1880 to 1890 is placed at 43.2 per cent, and from 1890 to 1895 at 22.6 per cent. The river now receives the sewage of the cities of Paterson, Passaic, Orange, and Newark, and the towns of East Orange, Bloomfield, Montclair, Harrison, Kearny, East Newark, and part of Rutherford. All these places are growing rapidly, and sewerage facilities for a number of other places are an admitted necessity of the early future. The commission therefore considers it beyond question that the pollution of the lower Passaic is sure to increase enormously unless remedial measures be taken.

As a summation the commissioners state:

(1) That the daily discharge of 70,000,000 gallons of sewage into the Passaic River below the Great Falls of Paterson is beyond its power to assimilate.

(2) That through the stench the pollution has become a nuisance to residents along the banks, and has caused depreciation of property and injury to health.

(3) That fisheries have been destroyed.

(4) That the river has ceased to be desirable for pleasure purposes, boating, bathing, etc., no longer possessing the park value which so generous a stream should afford the large population on its banks.

(5) That the use of the river for manufacturing purposes is suffering on account of the pollution.

(6) In short, that the pollution of the lower Passaic River appears to the commissioners to be completely established as a public nuisance, as injurious to health, and as an increasing menace to property interests from the Great Falls at Paterson to below Newark.

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[1] Abstract from report of Passaic Valley sewerage commission, pp. 10–11.

In discussing means of relief the commissioners state that the great progress in sanitary science of recent years has increased the demand for thorough methods of sewage disposal; hence it has been recognized in European countries, and throughout the thickly settled part of the United States, that methods of sewage disposal need a degree of care and thoroughness second only to the requirements of furnishing the same population with water and food. After reviewing the various methods of sewage purification the commissioners conclude that in the present case the conducting of the sewage to tidal waters is, on the whole, preferable. Their reason for this conclusion is, largely, that the available land areas in the Passaic Valley appear poorly adapted for irrigation and filtration processes. On this point the engineers to the commission, Messrs. A. Fteley and Charles E. A. Jacobson, state that the only lands within reach of sufficient area for irrigation works are the extensive meadows of the lower Passaic Valley, but unfortunately the character of the soil is so compact that, even with extensive and costly underdrainage, the amount of sewage which could be disposed of per unit of area would be so small as to require many thousands of acres; hence, Messrs. Fteley and Jacobson consider land disposal impracticable for the lower Passaic. They recommend the construction of an intercepting sewer at an estimated present cost of $6,500,000. The yearly cost of operation is placed at $125,000 in 1900 and $300,000 in 1930.

An extended series of chemical analyses made by Herbert B. Baldwin, chemist to the commission, is included in the report. In considering the effect of the sewage on the condition of the river, it is pointed out by Mr. Baldwin that the average discharge of sewage is a fairly constant quantity, but that the flow of the river is not. By way of illustrating this, we may point out that the flow of the Passaic River varies at Little Falls from a minimum of about 200 cubic feet to a maximum of about 20,000 cubic feet per second. The drainage area above Little Falls is 773 square miles. Whenever the river is either at or anywhere near its minimum flow, what may be termed the point of saturation is so far exceeded that the river inevitably becomes not only a nuisance, but a menace to health. On the one hand, the clearing of forests tends to decrease still further the minimum flow and to increase the length of the low-water period from year to year; on the other hand, the growth of towns and the extension of sewerage works tend to increase the pollution. Taking the two together, there is, therefore, a more rapid increase in actual stream pollution than is indicated by mere consideration of the percentages of increase of the quantity of sewage.

Moreover, the upper Passaic is the natural source of water supply for the north Jersey municipalities, and the probable taking of an appreciable part of the stream for such supplies will inevitably tend to aggravate existing conditions.

Chapter 83 of the Resolves of the Massachusetts Legislature of 1895 directed the State board of health to investigate the sanitary condi-

tion of the meadows on Neponset River, and submit the results of the examination, together with recommendations for the improvement of the sanitary condition of the meadows and the removal of the nuisance therefrom. The report of the board's engineers was made under date of October 1, 1896.

The Neponset Meadows, covering an area of 3,662 acres, of which little more than 600 acres appear to be in a condition adapted to agriculture, are subject to prolonged flooding nearly every year, and, with an increasing pollution of the stream, have become a serious public nuisance. The object of the report of the Massachusetts State board of health referred to is the abatement of this nuisance.

The Neponset River is connected with the Charles River by Mother Brook, which is legally entitled to receive one-third of the flow of Charles River. The drainage area of the Neponset River at its mouth, including one-third of the watershed of the Charles River above Mother Brook, is given as 180.3 square miles. The population of the several towns in the Neponset Basin above the lower end of the meadows was, in 1885, 15,097; in 1890, 17,361, and in 1895, 19,193. These towns are provided with public water supplies, but none of them have as yet a general system of sewerage.

The Neponset River may be divided into three portions: An upper portion, above the great meadows; a middle portion, including the meadows subject to overflow; and a lower portion, within the limits of the Boston metropolitan district.

The upper portion is about 10 miles in length, with a total fall of about 220 feet. Manufactories and mills are located throughout the valley, and the river is highly polluted by manufacturing wastes. The length of the middle portion is 11.25 miles. In much of this portion the river has very little fall and the flowing water is partially purified by dilution with water from purer tributaries and by sedimentation. The lower portion has considerable fall to tide water, and has high banks occupied by factories and dwelling houses. Practically all the water power of this section is made available by milldams. The minimum flow of the stream, as determined by the lowest level, reached in 1895, is about 54 cubic feet per second.

Chemical analyses of the water of the Neponset River were made by the Massachusetts State board of health in 1873, 1875, 1885, 1891, and 1895. A tabulation of the results shows a much more serious pollution in 1895 than in 1875. Thus, in 1875, at the Milton lower mills, free ammonia was 0.0112 part per 100,000; in 1891 it was 0.0274 part; and in 1895, 0.0526 part. In 1875 the albuminoid ammonia at Milton lower mills was 0.0171 part per 100,000; in 1891, 0.0329 part; and in 1895, 0.0342 part. Chlorine at Milton lower mills in 1875 was 0.46 part; in 1891, 1.18 parts, and in 1895, 1.47 parts.

The report states that, in order to improve the sanitary condition of the river and meadows, it will be necessary to prevent the further dis-

charge into the stream of domestic and manufacturing sewage, unless it has been previously purified sufficiently to prevent offense to sight or smell. A system of sewerage was provided for by chapter 406 of the Massachusetts acts of 1895, by means of which it will be possible in future to prevent the pollution of the river below the great meadows, after some provision is made whereby the diversion of sewage from the river into the sewers is made compulsory and the further discharge of manufacturing wastes is prevented.

The town of Hyde Park is located on the Neponset River, just below its junction with Mother Brook. The pollution in the region above at the present time is caused almost entirely by the discharge into the river of manufacturing wastes, generally from paper mills and tanneries. Investigations with reference to the purification of wastes of this sort were begun by the Massachusetts State board of health in the summer of 1895, and a résumé of the results will be found in the following pages. The published results indicate that it will be feasible to purify the manufacturing wastes satisfactorily at a cost sufficiently small to avoid crippling the manufacturing industries. A study of the question of the purification of the sewage of a number of towns naturally draining into the Neponset River in the upper valley shows that the necessary purification can be best accomplished by separate treatment upon land, as is done in many other towns in Massachusetts.

The removal from the river of the crude sewage of the manufacturing establishments, as well as that of the towns in the valley, will tend to improve the sanitary condition of the channel of the stream by preventing further deposition of organic matter upon the sides and bottom and in the numerous shallow bays and coves.

The report further states that, in order to improve the sanitary condition of the meadows, it will be necessary to lower the level of the water in the river sufficiently to permit the satisfactory drainage of the meadows and to prevent being flooded during the summer season. To accomplish this it is considered that the river should be deepened sufficiently to carry off the summer flows and still keep the water surface below the level of the meadows. Applying the run-off data of the Sudbury River watershed, for which a record covering twenty-one years is available, it appears that the river channel should be enlarged enough to enable it to carry at least 720 cubic feet per second, which would be sufficient for anything except a summer rainfall in excess of that of August, 1889, when the run-off of the Sudbury River for the month amounted to 2.55 inches on the watershed, the rainfall of the previous month of July being 8.94 inches and of the previous August 4.18 inches. The run off-of August, 1889, of 2.55 inches, was the largest for any summer month during the period 1875 to 1896, covered by the Sudbury measurements. In 1882 the August run-off of the Sudbury was only 0.10 inch. In 1883 the September run-off was 0.08 inch. In 1883 the total run off of the Sudbury for the summer months, June to

August, inclusive, was only 0.86 inch. In 1889 the total run-off of the summer months was 4.81 inches. According to the report of the engineer, an examination of the rainfall records of eastern Massachusetts for the period of thirteen years indicates that summer flows as heavy as in August, 1889, may be expected about once in ten to fourteen years; while for about two or three times in a century it may happen that the flow for some one of the summer months will be considerably in excess of that for August, 1889.

The plan for draining the Neponset Meadows includes, in effect, the cutting of a new channel across a number of sharp bends, thus considerably shortening the length and increasing the slope. It also includes removing the flashboards of the dam of the Mattapan Paper Mill, which is situated on the river about half a mile up the stream from the north line of the town of Hyde Park. The estimated cost of the river improvement, not including cost of land and water damages, is $127,115. It is also estimated that the increase in valuation of the 3,655 acres of meadow resulting from this improvement would amount to $101,330.

In concluding his report, Mr. Goodenough, the engineer of the State board of health, states that the gain in valuation of the meadows, produced by draining them, probably does not represent the full economic value of the improvement. By leaving the river and meadows in their present condition they become not only a source of annoyance, but a menace to the health of those living in the vicinity, and ultimately unfavorably affect the value of all real estate in the vicinity. Moreover, if a portion of the improved meadows should be utilized for market gardening, the value of such portion would be much greater than if used for hay and pasturage alone.

In order to show the great pollution to which streams in manufacturing districts are subject from the discharge of manufacturing wastes, we may further refer to the report on river pollution in Connecticut, by Prof. S. W. Williston, from which extracts have been made in Water-Supply and Irrigation Paper No. 3, first considering the case of Quinnipiac River. That stream has a drainage area of about 150 square miles, with a population thereon in 1890 of fully 40,000. Meriden, the chief city of the drainage area, had a population in 1880 of 15,540, and in 1890 of 21,652.

A measurement of the flow of the Quinnipiac River made August 3, 1888, gave about 7 cubic feet per second. A measurement on Monday, August 6, before the mills started, gave 5.5 cubic feet per second; at 10 a. m. the same day the flow was nearly 20 cubic feet per second. The rainfall is such that in ordinary years we may expect fairly uniform daily stream flows in the vicinity of Meriden.

In 1888 there were in Meriden 23 manufacturing establishments, with 5,708 employees, of whom 3,608 used water-closets.

In a year these manufactories produce the following amounts of polluting materials:

Polluting materials used by manufactories in Meriden, Connecticut.

Mineral acids	pounds..	891,700
Alkalies	do....	198,500
Mineral salts	do....	7,000
Inorganic and organic oils	gallons..	18,445
Asphaltum	pounds..	1,000
Soap	do....	7,000
Cotton waste	do....	2,000

The organic matter scoured from wool is stated at over 500 pounds daily. The total amount of manufacturing wastes turned into the stream is estimated at from 2½ to 3 tons daily, one-fourth of which is organic.

At Yalesville and Wallingford Professor Williston found 6 manufacturing establishments, with 1,060 employees, of whom 485 used water-closets. The polluting material used per year by the 6 establishments was reported as follows:

Polluting materials used by manufactories in Yalesville and Wallingford, Connecticut.

	Pounds.
Organic matter (about)	50,000
Acids	173,000
Alkalies	41,000
Minerals and mineral oils (about)	90,000
Total	354,000

The sewers of New Britain, Connecticut, drain partly into a tributary of the Quinnipiac River and partly into a tributary of the Connecticut River. The population of New Britain in 1880 was 11,800, and in 1890, 16,519. Professor Williston's canvass showed 12 establishments, with 3,075 employees, using water-closets which drained into Pipers Brook, a tributary of the Connecticut.

The following quantities of chemicals per year were discharged from these 12 establishments:

Polluting materials discharged from manufactories in New Britain, Connecticut.

	Pounds.
Metal salts	700,000
Free acids	100,000
Lime salts	35,000
Alkali salts	100,000
Soap	25,000
Fatty matter	100,000
Vegetable refuse	20,000
Total	1,080,000

Waterbury, the chief city on the Naugatuck River, in Connecticut, had, in 1880, a population of 17,806, and in 1890 a population of 28,646.

In 1887, 26 manufacturing establishments employed 7,571 persons, of whom 7,140 used water-closets.

The annual pollution from manufacturing wastes at Waterbury was placed as follows:

Polluting materials discharged from manufactories in Waterbury, Connecticut.

	Pounds.
Free acids	500,000
Metal salts	2,500,000
Alkaline salts	75,000
Soap	50,000
Fatty matters	200,000
Total	3,325,000

A large amount of interesting recent information in regard to river pollution in the United States is now available, but lack of space precludes further reference to it in this place.[1] The examples given will serve to illustrate the immense amount of polluting wastes that are daily being thrown into the rivers.

SEWAGE PURIFICATION AT MANUFACTURING ESTABLISHMENTS.

In England the pollution of streams from manufacturing wastes became very serious many years ago, and as the result of careful consideration of this special phase of stream pollution a number of sewage-disposal plants have been devised, especially with reference to purifying the sewage of each manufacturing establishment at the mill. A large amount of information in regard to such plants, with detailed plans, may be found in the fourth report of the Rivers Pollution Commission. As American examples, a number of cases cited by Mr. Clark in his report to the Massachusetts drainage commission, together with several recent ones, may be mentioned.

(1) The Wansuch Mills at Providence, Rhode Island, manufacture woolen and worsted goods extensively. The yearly amount of refuse contained in the waste water from this mill is stated to include about 64,000 pounds of dyestuffs, 1,000,000 pounds of alkali, 4,000 pounds of acid, 53,000 pounds of fuller's earth, and 400,000 pounds of grease. The waste water which contains this polluting material, and which originally flowed directly into West River, is stated as about 400,000 gallons a day. A dyeing and bleaching company located on the stream below the Wansuch Mills brought suit, alleging serious injury to its operations. After protracted litigation the supreme court granted a permanent injunction. In compliance with the injunction attempts were made to purify the waste water before permitting it to enter the river. For this purpose an acre and a half of land was prepared for filtration

[1] See the annual reports of the several State boards of health. The annual reports of the Provincial Board of Health of Ontario may also be referred to. As further illustrating the pollution of streams by mill wastes, reference may be made to the Eighty-third Annual Report of the Philadelphia Water Department (1885), pages 308, 309, where the detail of the daily wastes from an extensive carpet, blanket, and cloth mill may be found. The same data are also given on page 64 of Sewage Disposal in the United States. See also the report of the Second Rivers Pollution Commission.

by making furrows 4 feet apart on the surface. This process was fairly successful when first tried, but the land soon became clogged on the surface. The filtration process was then abandoned, although it seems clear from present information that with a larger area it could have been made successful. Purification by chemical precipitation was then adopted and has, so far as known, been continued since. For this purpose a set of six connected basins was excavated on the land previously used for filtration.

It is stated that about a barrel of lime is added to each 100,000 gallons of waste before pumping to the precipitation basins. This addition is made rudely, without either previously grinding or slacking the lime. The mill wastes flow continuously through the basins, with most of the deposition taking place in the first basin. The effluent from the last basin is said to appear to the eye about as foul as when it enters; this apparently indicates, in view of the satisfactory results gained elsewhere, defects in the practical management of the process. In the beginning sulphate of alumina was used as a precipitant, at a cost of about $6,000 per year for the whole amount treated, which, however, was considered too great an expense.

(2) At the Loraine mills, Saylesville, Rhode Island, a method of wool scouring is practiced by which the grease is recovered and most of the dirt is eliminated from the wash water before it is permitted to escape. The results at this mill indicate the recovery of about a ton of grease from each 18,000 pounds of wool washed. The cost of the plant for accomplishing this, not including buildings, was $2,500. The process is considered remunerative.

(3) Two mills in Millbury, Massachusetts, each scouring about 1,000 pounds of wool per day in the grease, retain the first scour in vats, which are cleaned periodically and their contents used as fertilizer. The process is considered remunerative at these mills.

(4) At the woolen mills of Robert Bleakie & Co., Hyde Park, Massachusetts, about 3,000 pounds of wool are scoured daily, the refuse from which, together with sewage and dyeing wastes, flows into a settling basin, whence the effluent passes into the stream. The settling basin consists of a cemented structure 80 feet long, 10 feet wide, and 3.5 feet deep; it is cleaned at intervals and the sludge is used for fertilizer, yielding for this purpose an estimated value of several hundred dollars a year.

(5) At Maxwell's tannery, Winchester, Massachusetts, a mechanical filter is used for straining bark and coarse lime from tannery wastes. The filter consists of a wooden box about 4 feet wide, 2 feet deep, and 60 feet long, divided into compartments filled with hay, through which the waste water filters. The effluent generally is clear, but of a deep mahogany color.

(6) The Nemasket mills at East Taunton, Massachusetts, applied to the State board of health in 1891 for advice with reference to disposing

of the sewage of the mill. The board advised that the waste water from the sinks be kept entirely separate from other wastes and conducted to a tight cesspool with an overflow therefrom into a filtering trench on the bank of the river. Also, that privies be provided in which all excrementaceous matters, both solid and liquid, be retained in water-tight vaults, to be cleaned from time to time, and the deposits buried in the ground not less than 100 feet from the Taunton River. The board expressed the opinion that by carrying out this plan the water supply of the city of Taunton, which is taken from Taunton River below the Nemasket mills, would not be contaminated by the mill wastes.

(7) The Menominee River Valley, in Wisconsin, adjacent to the city of Milwaukee, has been badly polluted for a number of years by wastes from large manufacturing establishments as well as from the public institutions of Milwaukee County. In 1893 the Wisconsin legislature instructed the State board of health to prepare plans and estimates for a sewerage system to serve this district. It also enacted further legislation, requiring all sewage to be filtered or otherwise purified to the satisfaction of the State board of health before being discharged into the stream. The act, however, failed to provide funds for preparing the plans, but most of the manufacturing establishments and public institutions have voluntarily introduced some method of treating their sewage. A recent letter from Dr. U. O. B. Wingate, secretary of the Wisconsin State board of health, indicates that the results obtained have been hardly satisfactory on account of adverse decisions of the Wisconsin courts[1] as to the powers of the State board, which have operated to prevent such supervision of sewage-disposal projects in Wisconsin as is now common in the more advanced States of the East and middle West.

The following are some of the particulars of the works actually constructed. At Schmidt's curled-hair works the solid matter of the liquid wastes is first screened out and the effluent then discharged upon porous soil, where it disappears. A similar system is in operation at McBride's sanitarium.

The National Soldiers' Home, with over 2,000 inmates and a daily flow of sewage of about 270,000 gallons, constructed an intermittent filtration system, the permanent success of which, however, is said to be doubtful because of the character of the soil of the filter areas.

At the shops of the Chicago and Northwestern Railway Company at Merrill Park a furnace has been provided for cremating the excrements.

The public institutions of Milwaukee County and the Miller Brewing Company have constructed combined chemical precipitation and mechanical filtration plants. The county institutions consist of a hospital, almshouse, two insane asylums, etc., having in all over 1,000 inmates. The flow of sewage is placed at from 250,000 to 400,000

[1] See also Sixteenth Ann. Rept. Wisconsin State board of health.

gallons a day. The sewage is first treated with lime and sulphate of alumina, and is subsequently filtered. The works are said to receive daily attention from a chemist, and thus far have furnished a clear effluent, free from odor, which does not undergo a secondary decomposition. However, according to information in Engineering News of January 13, 1895, it appears that this plant is not doing the work as thoroughly as it should because of overcrowding and too infrequent cleaning. The plant was originally designed to treat 480,000 gallons of sewage in twenty-four hours, which would certainly be a very large quantity from 1,000 inmates, even at insane asylums. If the present works actually have a capacity of 480,000 gallons in twenty-four hours, or, what is the same thing, a capacity for treating 480 gallons per capita per diem, they certainly ought to take care of the sewage from these institutions. The mechanical filter is said to be composed of limestone, Florida moss, and iron manganese. We understand that the process is patented, but probably does not represent the best practice in sewage purification at the present time, which may be the real reason for its failing to do the work properly.

The Miller Brewing Company, which produces perhaps 150,000 gallons of sewage a day, has a similar plant, the effluent from which is stated to be so unsatisfactory as to undergo secondary decomposition.

In a letter to Engineering News dated January 21, 1895, Dr. Wingate, the secretary of the Wisconsin State board of health, states that two of the plants which have been built in the Menominee Valley are satisfactory in their construction, but their management is unsatisfactory. He also states that the managers of the different institutions and manufacturing establishments have apparently the idea that constructing a plant is all that is necessary, that they have not furnished the necessary agents and help to keep the plants in proper condition, and that they have not managed them properly.[1]

Experience abroad has fully shown that purification works require attention; indeed, our own experience on this point is now so full, that it seems unnecessary for Americans to experiment further in that direction.

(8) In Ohio stream pollution from manufacturing wastes has assumed some importance, and the State board of health of that State has investigated a number of cases of such pollution, one of which may be referred to here. The Scioto Straw-Board Company, of Kenton, Ohio, discharges the wastes from its mill into the Scioto River. Complaints having been made to the State board of health that such discharge caused a public nuisance, an investigation was made in the summer of 1886. The following analyses of water from the Scioto River at Kenton indicate the extent of the pollution. In considering the significance of

[1] In a letter to the author, dated August 6, 1897, Dr. Wingate states that a drainage commission has been appointed to report to the next legislature, which will consider the whole question of Menominee Valley sewage disposal.

these analyses it should be understood that the Scioto River at Kenton is little more than a respectable brook. The average fall does not exceed 1 foot per mile for 30 miles. Analysis No. 1 is water from the Scioto River above the mill; No. 2, water from below the mill, and No. 3, from La Rue, a few miles below.

Analyses of water from Scioto River near Kenton.

[Grains per gallon.]

Number.	Lime.	Chlorine.	Mineral.	Organic and volatile.	Total solids.
1	8.98	0.25	20.30	9.68	29.98
2	63.32	6.49	84.09	130.63	214.72
3	13.33	1.45	31.26	18.19	49.45

So far as can be learned, the great increase in pollution of the stream did not affect the health of people living in the vicinity, although the fish in the stream were killed and there was at time of low water a serious effluvium nuisance. The remedy was the construction of a settling tank of from 3 to 5 acres. As to whether or not this has proved satisfactory there is no information at hand.[1]

(9) The waste waters at Tid's tannery, Stoneham, Massachusetts, were treated chemically during the years 1894 and 1895. The following results were obtained in the latter year. The total quantity of sewage pumped was 4,990,924 gallons, to which were applied as a precipitant 71,760 pounds of sulphate of alumina. The sludge amounted to 648,820 gallons, or 13 per cent of the sewage. It was disposed of to neighboring farmers, who carted it away for fertilizer. These works were first operated in 1893, by the city of Boston, in order to protect the Upper Mystic Lake.

(10) At Fitzgerald's tannery, also in Stoneham, Massachusetts, a series of precipitation tanks were constructed by the owner in 1895, arranged in such manner that the heavy particles of waste matter will settle as the sewage flows from one tank to another over separating partitions. In 1895, however, the quantity of sewage having increased to about 10,000 gallons daily in August, it was found necessary to use more chemical than the lime naturally present in the sewage. The owner thereupon constructed a vat for chemicals, and the Boston water department furnished and applied sulphate of alumina to the extent of 10,520 pounds from August, 1895, to January, 1896. The effluent from both these tanneries in Stoneham, while still highly colored from the tan bark, is stated to be on the whole fairly satisfactory. The use of a larger amount of chemicals would remove an additional amount of color, but at such increased cost as is considered not to be justified by the circumstances.

[1] The Ohio State board of health issued in 1898 a Preliminary report of an investigation of rivers, etc., of Ohio, which gives much information about the waters of that State.

MASSACHUSETTS EXPERIMENTS ON THE PURIFICATION OF FACTORY WASTES.

In the report of the Massachusetts State board of health for 1895 the results of investigations as to the disposal of waste liquors from various industrial processes are given. Among others may be found a discussion of the results obtained in the purification of the waste liquors from paper making, wool scouring, and tanning.

PAPER-MILL WASTES.

The experiments on purification of paper-mill wastes included the application for some time to a filter containing 60 inches in depth of sand of the effective size of 0.25 millimeter of the waste liquor resulting from cleansing rags in a paper mill by means of a boiling solution of caustic soda and lime. The rags cleaned are of all kinds and colors, and the resulting liquor, as stated, is very highly colored. It was applied to the filter at an average rate of 65,500 gallons per acre daily, with the result of great improvement in the appearance and analysis, although the effluent as it flows from the filter is still highly charged with organic matter in solution. The following is the analysis of the applied liquor: Free ammonia, 2.3 parts per 100,000; albuminoid ammonia, 4.1 parts; chlorine, 20 parts; oxygen consumed, 140 parts. The effluent shows: Free ammonia, 1.8 parts per 100,000; albuminoid ammonia, 2.29 parts; chlorine, 12.59 parts; nitrogen as nitrates, 0.105 part, and as nitrites, 0.0067 part; oxygen consumed, 84.36 parts. The nitrates and nitrites in the applied liquor are nil. It is clear, therefore, that some considerable nitrifying action has taken place in the filter, but it is the opinion of the board that the degree of alkalinity is so high as to prevent the full effect of nitrification.

WOOL-SCOURING WASTES.

The waste liquors of wool scouring were applied to a filter with the same depth of sand and effective size of grains as in the previous case, at the rate of 17,000 gallons per acre daily. The results, so far as obtained, show that while a considerable improvement of such a liquor can be obtained by intermittent filtration, still, owing to clogging of the upper layers of the sand, it appears desirable that a preliminary treatment, to remove a part of the dirt and fatty matters before filtration, should be applied. The average analyses of the waste liquor from wool washing and of the effluent were as follows: The applied liquor contained 17.3 parts of free ammonia per 100,000; albuminoid ammonia, 43.1 parts; chlorine, 60.13 parts; oxygen consumed, 232 parts. The effluent contained: Free ammonia, 27.8 parts per 100,000; albuminoid ammonia, 8.3 parts; chlorine, 47 parts; nitrates, 0.28 part, and no nitrites; oxygen consumed, 90 parts. The applied liquor was entirely free of both nitrates and nitrites. A refiltration of the effluent

from the preceding experiment on waste liquor from wool scouring was made through two filters, one containing 60 inches in depth of sand of the same effective size of grain as before and the other containing 60 inches in depth of coke breeze. The effluent was applied to the two filters for three months, at the rate of 50,000 gallons per acre daily. The liquor passed through both the sand filter and the coke breeze very little changed, thus showing not only the stable character of the organic matters present, but that the high degree of alkalinity was probably prejudicial to nitrification.

An experiment was also made as to the treatment of the waste liquor from wool scouring by the preliminary precipitation of the fat and dirt by means of calcium chloride, followed by intermittent filtration. This treatment gives an almost complete clarification of the liquor, but it passed through a filter 5 feet in depth, with effective size of sand grain of 0.25 millimeter, with very little change.

TANNERY WASTES.

In order to test the efficiency of intermittent filtration as applied to tannery wastes, an experimental filter has been set up at Norwood, Massachusetts. On account of the conditions imposed by the location, the filter has only 2 feet of sand, the effective size of the sand grain being 0.14 millimeter. The sewage applied is a mixture of the waste liquors from all the processes carried on in the tannery; and it was applied to this shallow filter at an average rate of 55,000 gallons per acre daily. The results obtained were as follows: The applied sewage contained 3.1 parts of free ammonia per 100,000; albuminoid ammonia, 3.16 parts; chlorine, 312 parts; nitrates, 0.16 part; nitrites, 0.0015 part; oxygen consumed, 55 parts. The effluent contained: Free ammonia, 2.34 parts per 100,000; albuminoid ammonia, 0.6 part; chlorine, 290 parts; nitrates, 1.05 parts; nitrites, 0.01 part; oxygen consumed, 7.5 parts.

This sewage is said to be very strong and offensive, containing decaying animal tissues and the bran added to cause fermentation. It is also colored by the dyes used in finishing the hides, which, after a few weeks, the filter failed to remove completely. The applied sewage did not contain any amount of the spent tan liquor. The antiseptic qualities of the tannic acid would, without doubt, be very prejudicial to nitrification.

In cleaning hides a large amount of lime is used, in consequence of which in large tanneries there is an almost continuous stream of lime water flowing into and mixing with the other waste liquors. By properly arranged settling tanks and the regulation of this lime water, it is the opinion of the Massachusetts board that a large percentage of the sludge could be precipitated out. Experiments show that probably 60 per cent of the organic matter can be removed in this way, although even then the resulting supernatant sewage would still remain very rich in organic matter in solution.

The supernatant sewage from such treatment was applied to a small filter at the average rate of 120,000 gallons a day. After several months' operation this filter is stated to be in a state of active nitrification, giving a clear and nearly odorless effluent. It is the opinion of the Massachusetts board that by treatment of tannery sewage on this line it may be efficiently purified by filtration.

DYESTUFFS.

Among the many experiments carried out at Lawrence, perhaps as interesting as any, are those relating to the filtration of sewage containing dyestuffs. This division of the sewage question is specially interesting because of the large number of manufacturing establishments at various places, the refuse from which usually passes without treatment into streams. In England this phase of sewage purification became of considerable importance early in the present century, because, generally speaking, the streams of England are small, and even sixty years ago a number of them had become badly polluted by the waste dyes from woolen, cotton, and other fabric manufacturing establishments. As illustrating the conditions twenty-five years ago, the Second Rivers Pollution Commission gives in its third report a reproduction of a memorandum written with the water of the river Calder at a point where the Wakefield sewer enters that stream. This memorandum reads as follows: "Dedicated without permission to the local board of health, Wakefield. This memorandum written with water taken from the point of junction this day, between the river Calder and the town sewer. Could the odor only accompany this sheet it would add much to the interest of this memorandum."

The condition of the river Calder has been improved in recent years by the construction of a number of sewage purification works along its banks, although when seen by us in October, 1894, it was still far from being a limpid stream.

Without going into the detail of the Massachusetts experiments on the filtration of various dyes used in fabric manufacturing, we may simply state that indigo extract, logwood extract, alizarin base, archil B, rose azurine, benzo-azurine, methyline blue, orange 2 R, magenta, malachite green, and scarlet 2 R, when applied at varying rates—from 335,000 gallons per acre of archil B to 1,280,000 gallons per acre of methyline blue—gave an effluent absolutely free from color. Scarlet 2 R applied at the rate of 1,076,000 per acre gave an effluent as highly colored as the applied sewage, but when applied at the rate of 720,000 gallons per acre the effluent was without color. Patent blue, when applied at the rate of 56,000 gallons per acre, gave a slight color; it also gave a slight color when applied at the rate of 160,000 gallons per acre, but when applied at the rate of from 335,000 gallons per acre to 960,000 gallons, it gave, in each case, a strongly colored effluent.

Indigo extract, logwood extract, alizarin base, and archil B are dilute

colors. The others are coal-tar colors in concentrated form. In most of the experiments the removal of the color, as already stated, was complete, as tested by viewing the effluents in tubes of from 200 to 600 millimeters depth.

Considering the large quantities of dyestuffs applied in these experiments, the conclusion may be drawn that dyes as likely to exist in ordinary city sewage are easily amenable to filtration treatment.

SPECIAL EXPERIMENTS.

In the course of the experiments at Lawrence a number were made as to the effect of antiseptics, as well as other substances, upon nitrification. Some of the more important of these experiments may be briefly referred to.

(1) For several weeks a considerable quantity of egg albumen, a substance nearly insoluble in water, was applied in one of the experimental tanks, the object being to determine to what extent it would be rendered soluble and converted into free ammonia. The indications of the first experiment were that about 61 per cent of the total nitrogen contained in the albumen applied was rendered soluble and converted into nitrates. A repetition indicated that possibly 90 per cent of the total nitrogen of the albumen was converted into nitrates.

(2) To one of the experimental tanks, which at the time of the first application was giving a perfectly nitrified effluent, a solution of ammonium chloride, in water containing 1 part of ammonia per 100,000, was applied in place of the sewage. Enough sodium carbonate was mixed with the ammonium chloride solution to combine with the chlorine of the ammonium chloride, and also with the nitric acid equivalent to the ammonia. Nitrification was complete from the first, the effluent being not only free from ammonia, but containing nearly all the nitrogen applied, as nitrates. The strength of the solution was gradually increased until it contained 34 parts per 100,000 of ammonia, after which complete nitrification was not at once obtained, but finally a nearly complete nitrification resulted.

(3) Experiments as to the the effect of an excess and deficiency of alkali were also made, showing that with alkali in excess nitrification was not in the least interfered with, but with a deficiency the process apparently stopped with the production of an enormous quantity of nitrites.

(4) Experiments as to the effect of acid upon nitrification were made, which showed that sewage containing a large percentage of sulphuric acid may have a major part of its nitrogenous constituents removed for a considerable time. If we are dealing with a sewage which contains moderate quantities of sulphuric acid occasionally, we may expect to purify it by intermittent filtration without any ill effects; but if the sewage contains sulphuric acid regularly, the acid should be neutralized by the addition of lime or some other alkali.

(5) Experiments as to the effect of common salt showed that when common salt was present in such quantity that the chlorine amounted to 1,200 parts per 100,000 the nitrification was quickly checked and the common-salt solution passed through the filter almost unchanged. If, however, common salt be added gradually, so that the filter may have the opportunity to adapt itself to the work required of it, the result was found to be very different. In an experiment of this character it was ascertained that with gradual increase of the common-salt solution nitrification continued. The practical result arrived at was that sewage containing a considerable quantity of common salt as one of its regular constituents may be purified by intermittent filtration without difficulty.

(6) Experiments as to the effect of sugar upon nitrification showed that if a considerable quantity of sugar is applied to intermittent filtration it will cause a decrease of nitrification. If, however, the filter can be gradually adapted to the special work of nitrifying sugar, the nitrification will finally become nearly as complete as when sugar is absent.

MECHANICAL ANALYSES OF SANDS.

The selection of the filtering materials is a very important point in constructing a filter. The Massachusetts State board of health has developed a method of sand analysis by which different sands may be compared and from their relative coarseness their efficiency as a filter material be foretold.

SIZE OF GRAIN.

As described in the twenty-third annual report of the board, the sand is first sifted through a series of sieves, each about twice as fine as the one next coarser. The sand passing the finest sieve is divided into several portions by beaker elutriation. Each portion is weighed, and the range and size of particles is determined either by micrometer measurement of the smaller particles or by computation of the diameters of larger particles by their weight. The diameters of all particles are taken as nearly as possible at the diameter of a square of equal volume. In each case the diameters are expressed in millimeters. As illustrating the results of such mechanical analyses in their application to filter material, we may quote the following as the percentage statement of the fine material used in experimental filter No. 5. In this filter the material with mean diameter less than 12.6 millimeters amounted to 99 per cent of the whole; material with less diameter than 6.2 millimeters to 96 per cent of the whole; mean diameter less than 2.2 millimeters, 92 per cent; mean diameter less than 0.98 millimeter, 89 per cent; mean diameter less than 0.46 millimeter, 80 per cent; diameter less than 0.24 millimeter, 67 per cent; diameter less than 0.12 millimeter, 51 per cent; diameter less than 0.06 millimeter, 33 per cent; diameter less than 0.03 millimeter, 16 per cent; diameter less than 0.01 millimeter, which would represent the organic matter, 6 per cent.

We have an example of the mechanical analysis of a coarse sand in the case of sand from filter No. 1. In this filter the material with mean diameter less than 12.6 millimeters amounted to 100 per cent of the whole; material with diameter less than 6.2 millimeters, to 97 per cent of the whole; mean diameter less than 2.2 millimeters, 85 per cent; mean diameter less than 0.98 millimeter, 53 per cent; mean diameter less than 0.46 millimeter, 7 per cent; mean diameter less than 0.24 millimeter, 1.5 per cent; mean diameter less than 0.12 millimeter, 0 per cent.

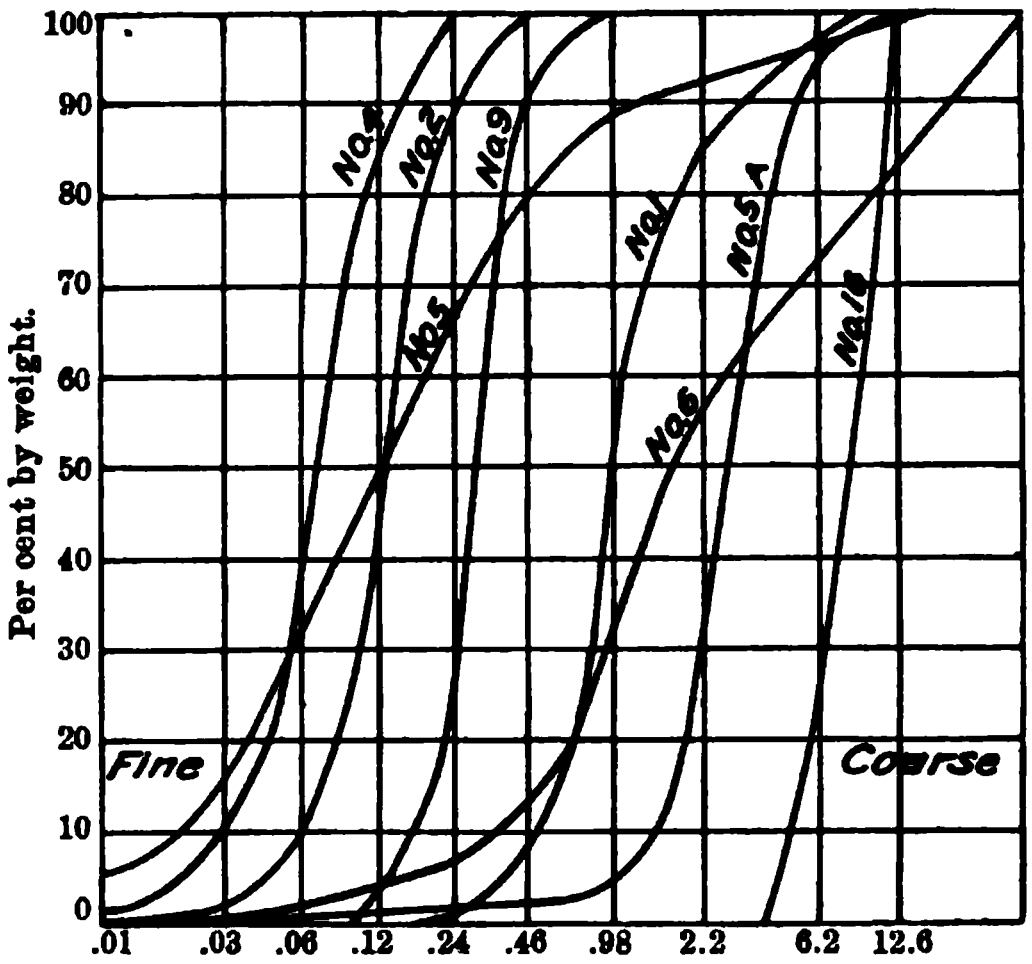

FIG. 1.—Mechanical composition of materials available for sewage filtration.

In the same way the results of the mechanical analysis of other sands used in the Lawrence experiments are expressed in the reports.

In order to compare the results of the mechanical analyses of the several sands experimented with as well as their relative values for filtration, we include the accompanying diagram, fig. 1, derived from the Massachusetts reports. The lines representing the diameters are spaced according to the logarithms of the diameters of the particles, as in this way materials of corresponding uniformity in range of size of particles give equally steep curves, regardless of the absolute size of the particles. The materials indicated by fig. 1 are stated by Mr. Hazen to include the whole range of the sands available for sewage purification.

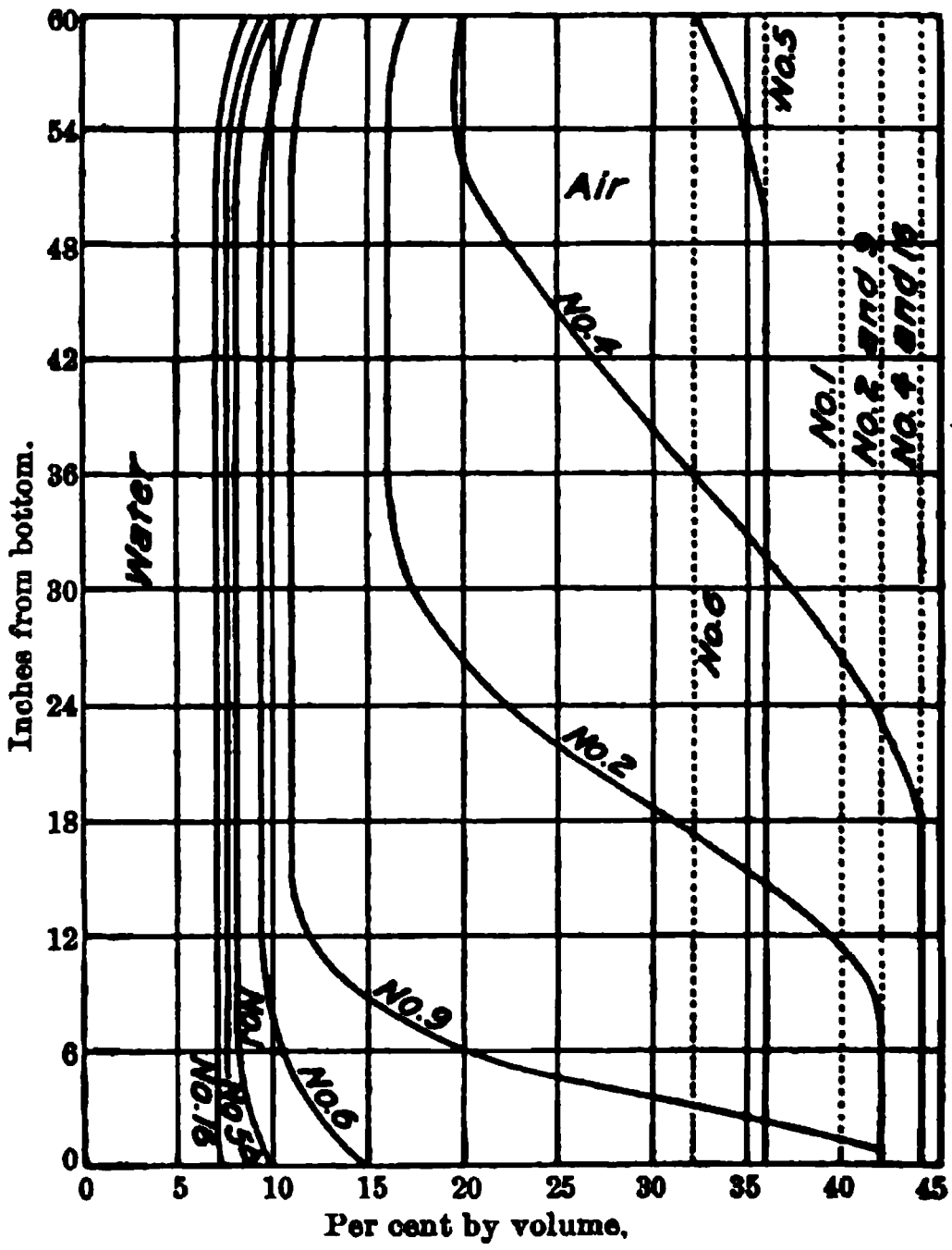

FIG. 2.—Air and water capacities of sewage filter materials. Full lines represent water capacity and dotted lines air capacity.

AIR AND WATER CAPACITIES OF SAND.

In order to estimate the filtering capacity of any given material, it is important to understand the air and water capacity of the filtering material when drained, the term "water capacity" being taken to designate the amount of water retained in the interstices after thorough draining. It is clear from what has preceded that the efficiency of the filtering process must depend largely upon these two elements. In fig. 2, also derived from the Massachusetts reports, the air and water capacities of the same materials illustrated by fig. 1 are shown, though in studying this diagram it should be borne in mind that the curves for air space and water capacity can be taken only as general averages, because the tenacity of the material can be varied greatly in packing. It is obvious that the amount of water will depend not only upon the closeness of the packing but also upon its uniformity, the tendency always being toward an increase of the water capacity. It will also depend at any given time upon the amount of organic matter stored from the material filtered. The water capacity will also depend largely upon the size of the particles, the finer sands holding much water, especially at the bottom, while with coarse sands the amount held will be nearly constant from top to bottom.[1]

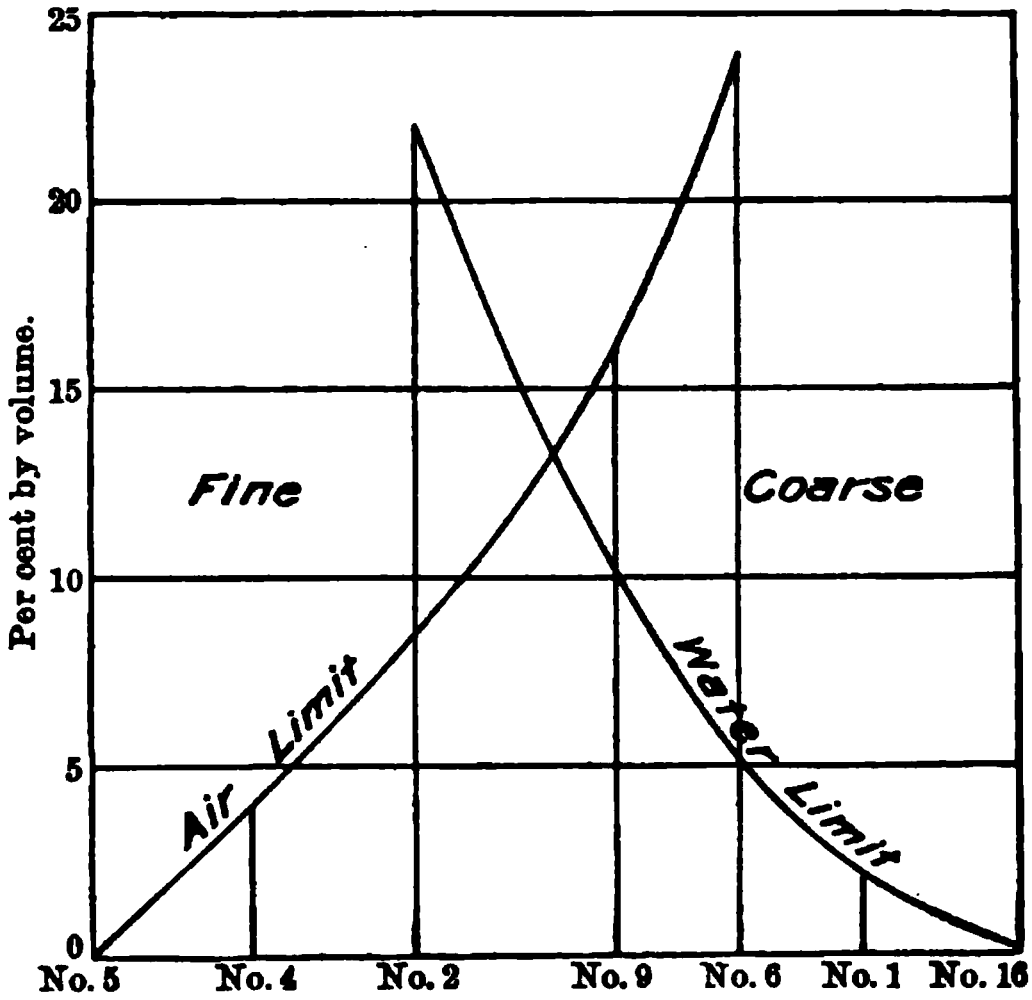

FIG. 3.—Limitation of size of single dose by air and water capacities.

LIMITATION OF SIZE OF DOSE.

The diagram, fig. 3, also taken from the Massachusetts reports, will illustrate the range of capacity with different materials in this particular. This figure illustrates the limit of size of a single dose with reference to air and water capacities. The various materials are indicated by vertical lines, while the per cent of total volume is indicated by horizontal lines, the lower portion of the two curves showing the maximum dose for any given material which can be applied at one time with good results. If the dose is greater than that indicated in the curve of water limit, it is probable that some will pass the filter before

[1] Reference to the twenty-third annual report of the Massachusetts board will furnish a discussion of these important practical questions in full detail.

complete purification. If the air limit is exceeded, the oxygen in the filter is liable to be exhausted before the oxidation is complete.

In the line of these studies the Massachusetts reports give a table showing the doses proved to be adapted to the various materials under the most favorable conditions of management. For material No. 16 of the preceding diagrams, as actually applied in practice at the experiment station, the dose was 2,800 gallons per acre, applied 500 times a week, this amount giving a daily average of 200,000 gallons per acre. For material No. 1 the size of dose is 40,000 gallons, applied 18 times a week, giving an average daily amount of 103,000 gallons per acre. For material No. 6 the size of dose is 70,000 gallons per acre, applied 6 times a week, giving a daily average of 60,000 gallons per acre. For material No. 9 the size of dose is 120,000 gallons an acre, applied 6 times a week, giving a daily average of 103,000 gallons per acre. For No. 2 the dose is 140,000 gallons an acre, 3 times a week, giving a daily average of 60,000 gallons per acre. For No. 4 the dose is 80,000 gallons, 3 times per week, giving a daily average of 34,000 gallons per acre. The depth of the material to which these applications were made was in every case, with the exception of No. 6, 5 feet; for No. 6 the depth was 4 feet.

As stated in the report, it must be borne in mind that the above figures are applicable only to clean materials under favorable conditions, and that in order to apply large doses permanently with good results the surface material must be occasionally renewed, as already discussed.

PURIFICATION OBTAINED BY INTERMITTENT FILTRATION.

As to the degree of purification obtained by intermittent filtration, the Massachusetts experiments show that very high degrees are reached easily. By way of illustrating the matter we may simply cite that city sewage has been purified to the extent of removing from 95 to 99.5 per cent of the polluting material. Sewage containing from 500,000 to 1,000,000 bacteria per cubic centimeter has been experimentally so far purified of bacteria that the effluents have frequently contained as few as from 25 to 100 bacteria per cubic centimeter. In order to appreciate this degree of bacterial purification we may consider that well waters in common use frequently contain from 2,000 to 3,000 bacteria per cubic centimeter. As regards chemical and biological considerations there is therefore no reason why such sewage effluents are not fit to drink.

SUMMARY OF MASSACHUSETTS EXPERIMENTS.

The body of information in regard to sewage purification by intermittent filtration which is presented in the several reports of the Massachusetts State board of health has become so extensive that one must be an expert to keep in mind the many interesting and valuable results brought out. As assisting the general reader, who may not care to travel through the several thousand pages of matter given in these reports, reference may be made to the very excellent summary of

the results obtained from intermittent filtration during seven years' experimentation, which appears on page 497 of the report of 1894, where may be found brief statements of yearly averages of the various kinds of filters experimented upon, as well as an outline of the most important features in the operation of each filter.

In concluding, it is pointed out that—

(1) The qualitative efficiency of the filters is lower in winter than in summer chiefly because of the inactivity of the nitrifying organisms when exposed to low temperature. The indications at present are that it is not advisable to allow exposed filters to rest in winter, even for limited periods.

(2) Qualitative deterioration is a serious matter in winter, because nitrification can not be promptly reestablished as in summer.

(3) It has been learned, however, that when nitrification is active at the beginning of winter it may by proper treatment be preserved during the cold season. To this end frost should not be allowed to penetrate into the interstices of the filters.

(4) The warmer the sewage, within limits, the better the results. Where high degrees of purification are imperative in winter the sewage may be heated to a temperature of 100° F. We may conclude, then, that the arrangement of the filter bed should be with reference to preserving, so far as possible, the heat actually present in the sewage as it arrives in the filter. For this purpose the trenching of the filter area is especially efficient, because it concentrates the heat, thus aiding in preserving the biological process in a state of efficiency.[1]

(5) In any case sewage should be so applied as to penetrate all portions of the filter, as otherwise the passage through will be rapid and irregular, thus tending to a low degree of purification.

(6) The composition of sewage, particularly as regards the kind of sewage, is a much more marked factor in winter than in summer. This is true even in the case of experimental filters, where special lines of treatment to keep the filters in operation are feasible.

VALUE OF COMMERCIAL FERTILIZERS.

In order to indicate the theoretical value of the nitrogen, phosphates, and potash of crude sewage, the following statement of trade values of fertilizing ingredients in raw materials and chemicals of commercial fertilizers, as used by the agricultural experiment stations of the country, is included. The valuations obtained by the use of these figures agree fairly well with the average retail price of standard materials. The price per pound, in cents, is as follows;

Value of chemical ingredients in commercial fertilizers.

	Cents.
Nitrogen in ammonia salts	17
Nitrogen in nitrates	15.5
Organic nitrogen in dry and fine-ground potash, meat, and blood, and in high-grade mixed fertilizers	17.5

[1] For an estimate in detail of the cost of heating sewage see Rafter and Baker's Sewage Disposal in the United States, p. 336.

	Cents.
Organic nitrogen in cotton-seed meal and castor pomace	16.5
Organic nitrogen in fine-ground bone and tankage	15
Organic nitrogen in fine-ground medium bone and tankage	12
Organic nitrogen in medium bone and tankage	9
Organic nitrogen in coarse bone and tankage	7
Organic nitrogen in hair, horn shavings, and coarse potash scraps	7
Phosphoric acid, soluble in water	6.5
Phosphoric acid, soluble in ammonium citrate	6
Phosphoric acid in fine bone and tankage	6
Phosphoric acid in fine medium bone and tankage	5
Phosphoric acid in medium bone and tankage	4
Phosphoric acid in coarse bone and tankage	3
Phosphoric acid in fine-ground fish, cotton-seed meal, castor pomace, and wood ashes	5
Phosphoric acid in fine-ground rock phosphate	2
Potash as high-grade sulphate in forms free from muriates (chlorides), in ashes, etc	5.5
Potash in kainit	4.5
Potash in muriate	4.5
Organic nitrogen in mixed fertilizers	17.5
Insoluble phosphoric acid in mixed fertilizers	2

Value of fertilizing ingredients in foods.

	Cents.
Organic nitrogen	17.5
Phosphoric acid	5
Potash	5.5

NECESSITY OF PURIFICATION OF SEWAGE AT TOWNS ON THE GREAT LAKES.[1]

According to statistics of the Eleventh Census, the basin of the Great Lakes, especially the area contiguous to Lakes Ontario, Erie, and Michigan, is, next to the Atlantic seaboard, the most densely populated area of the United States. Bordering on Lakes Ontario, Erie, and Michigan are great and rapidly growing cities from which all of the sewage now passes into these lakes. The surrounding regions are usually not greatly elevated above the lakes, and hence do not afford any opportunity for obtaining upland waters for municipal supplies. The water supplies of towns on the Great Lakes are not only now almost universally taken from these bodies of water, but must necessarily continue to be so taken in the future. At present the sewage of the Great Lake cities is discharged without treatment into the same bodies of water from which the public water supplies are taken. An exception is the city of Rochester, which wisely brings its water supply by gravity from Hemlock, an inland lake about 30 miles distant; but Buffalo, Erie, Cleveland, Detroit, Chicago, Milwaukee, and many other towns take their water supplies in the manner stated. Without going into details for all the Great Lakes, we will state that Lake Michigan alone receives at the present time the sewage of municipalities and small towns aggregating over 2,000,000 people, and this population is rapidly

[1] This chapter is presented to illustrate the vast importance which sewage-purification studies are rapidly assuming in the United States.

increasing, having about doubled in ten years. A similar increase in population has taken place in the cities and towns tributary to the lower Great Lakes. Thus, Detroit had a population in 1880 of 116,340, and in 1890, 205,876. Cleveland showed a population in 1880 of 160,146, and in 1890, 261,353. In 1880 Buffalo had 155,134; in 1890, 255,664.

EFFECT OF SEWAGE ON LAKE WATERS.

The modern studies all indicate that when organic matter in increasing quantities is continually poured into a body of fresh water, a point is quickly reached beyond which the body of fresh water. whether it be lake, pond, or running stream, has no power of further assimilation. Chemical analyses of the waters of the Great Lakes show a gradually increasing contamination during the last fifteen or twenty years. The evidence is multiplying that, with the present increase in population, the Great Lakes, if they continue to be used as common sewers, will soon become totally unfit for use as drinking water. When this time arrives one of two alternatives must be followed—either every source of water supply must be filtered or the sewage of the towns must be efficiently purified before it is allowed to flow into the lakes. In some cases the conditions are such that both remedies must be applied.

The question of the limit of permissible contamination of these waters is very likely to arise, either as to the number of bacteria, the microscopical forms, or the chemical constituents. The answer is, it will depend entirely upon the environment. If a given water is known to receive sewage, a very small quantity of organic matter, indicated either by the free and albuminoid ammonias or by the loss on ignition, may justly cast suspicion upon it. If, on the other hand, there is no sewage contamination and the organic matter present is clearly shown to be due to natural drainage from the surface of the ground, the ammonias and loss on ignition have very little significance. As to the number of bacteria, Dr. Koch, the originator of the method of gelatin cultures, laid down the principle that potable waters might show, when examined immediately on collection, as high as 1,000 bateria per cubic centimeter without condemning them. The more recent studies, however, tend to show that Koch's original figure was somewhat too high, and at present it is considered that a sanitarily unobjectionable water ought not to show more than 300 to 500 forms per cubic centimeter. When the number rises much above that amount the water is open to suspicion.

Bacteriological examinations of the water of the Great Lakes show that the water at Detroit is superior for domestic use to that at Buffalo. The difference must be ascribed to the vast amount of sewage poured into Lake Erie, and the incapacity of that body of water to purify itself thoroughly before reaching the Buffalo intake at the head of the Niagara River.

If space permitted, many analyses of the water of the Great Lakes might be quoted which show, on the whole, a gradually increasing contamination.[1]

One point of interest about the water supply of the city of Milwaukee may be noted. During the navigation seasons of 1892, 1893, and 1894 the United States Weather Bureau carried out an extended series of float experiments in order to determine the actual trend of the currents of the Great Lakes. As regards Lake Michigan, the experiments clearly show that there is a rapid whirl at the south end, with a strong current passing north along the east shore, while along the west shore the current flows south. This disposition of the currents undoubtedly favors the water supply of the city of Milwaukee, giving to that city water with less organic contamination than it would receive, either if there were no current or if the current set from the south to the north along the west side, bringing to Milwaukee the contaminated water of the Chicago lake front. As the currents now flow Chicago receives the contaminated water of Milwaukee.

At Chicago the barbarous practice of turning the sewage of a great city into the body of water from which the public water supply is taken has resulted so disastrously as to lead to the construction of what is known as the Chicago drainage canal, by which it is expected to deliver the greater part of the Chicago sewage into the head waters of the Illinois River, and so finally into the Mississippi. Partial investigations, made several years ago under the auspices of the Illinois State board of health, indicated a very rapid purification of the sewage-contaminated waters of the present Illinois and Michigan Canal as they flow to the south. The investigation has not been carried far enough to indicate what the results will be upon the Illinois River and the Mississippi when the project shall have been completed and the sewage of Chicago largely turned south. The known facts as to the increasing contamination of the Great Lakes would indicate the vast importance of determining the ultimate effect of such discharge. In considering such effect, moreover, one should bear in mind the difference between running streams and lakes with only slight currents.

DANGER OF WINTER TYPHOID.

As regards water supplies from the Great Lakes at places so far north as to render probable the closing of the lakes by ice nearly every winter, there is another serious view connected with taking water either contaminated or liable to be contaminated by sewage, which has thus far been generally overlooked. So long as the lakes remain open, usually the antagonisms of the aerobic forms of microbic life will be sufficient, except in cases of extremely severe contamination, to keep typhoid and other anaerobic forms mostly in subjection; but as soon as the lake surfaces are covered with ice an entirely new set of conditions

[1] The author has in preparation a paper on Water Supplies from the Great Lakes, in which full [illegible] will be given.

exist; the air is then excluded and the anaerobic forms develop at the expense of the aerobic. This undoubtedly explains the severe epidemics of winter typhoid which have occurred at Buffalo, New York; Lorain, Ohio; Windsor, Ontario; Ashland, Wisconsin; Duluth, Minnesota; Chicago, Illinois, and at a number of other places on the Great Lakes. The following are some of the particulars of these winter outbreaks:

In the latter part of February, 1894, on account of low water in the Niagara River, it became necessary to take the water supply of the city of Buffalo from an old inlet said to be in a current carrying the discharge from sewers higher up. From March 6 to 11, inclusive, the total number of typhoid cases reported was 36. On March 12, 26 new cases were reported. The next day the number was increased 100, and then by 88, 79, 52, and 25 on successive days, making a total of 406 cases from March 6 to 17, inclusive, and 370 cases in the six days from March 12 to 17, inclusive. These cases were mostly of such mild character that only 9 deaths were reported for the whole month. In March, 1893, only 4 deaths occurred, and in March, 1892, but 1.

The city of Lorain, Ohio, is located at the mouth of the Black River, which receives the sewage of Elyria, several miles distant. It also receives the sewage of Lorain, in which place sewers were first laid down in 1892, their use for water-closet drainage beginning in October or November of that year. The water supply of the town is taken from very near the end of the harbor jetties, where the sewage first has free access to the lake water. Lake Erie was closed with ice at Lorain during the months of January, February, and March, 1893. In March and April there was a serious epidemic of typhoid fever, 8 deaths occurring in a population of about 5,000. In 1895 the lake was again closed with ice during the months of February and March, and typhoid fever again became epidemic, there being 3 deaths in February, 2 in March, and 4 in April.

In February, 1896, typhoid fever became epidemic at Windsor, Ontario, a town on the Detroit River just opposite the city of Detroit. During the previous month of December, 1895, the total number of cases was 9; for January the total was 18; for February 82, and for March 13; making a total for the four months of 122. The cause of the outbreak is ascribed to the presence of the sewage of Walkerville in the Windsor water supply. The discharge of Walkerville sewage above the Windsor waterworks intake has been a source of controversy between Windsor and Walkerville for several years, and although more or less typhoid fever has existed at Windsor the outbreak in February, 1896, is the most serious winter epidemic thus far experienced there. As stated in the report of the Provincial Board of Health of Ontario, there was a severe freshet about January 25, 1896.

During the winter of 1894 a severe epidemic of typhoid fever occurred at Ashland, Wisconsin. Several hundred cases developed in a few weeks, and from the distribution there was every reason to ascribe

their origin to the condition of the city water supply, which is taken from Chequamegon Bay, an arm of Lake Superior, on which the city is situated. This bay is about 12 miles long, with an average width of 5 miles. It varies in depth from 8 to 36 feet. A large breakwater has been constructed to the northwest of the city, on the city side of which is located the mouth of the intake pipe of the public water supply, about a mile from the shore. This arrangement is unfortunate, because it permits the sewage and storm water of the city to flow directly over the mouth of the intake pipe.

In February, 1894, the ground was covered with 2 feet of snow. In the last week of the month there were heavy rains and warm weather, which in a few days melted all the snow and washed the accumulations of the winter into the bay. Typhoid fever broke out in from ten to fifteen days thereafter, and in a week after the first case made its appearance there were over 300 cases. The epidemic lasted about eight weeks, and finally terminated with 450 cases and 26 deaths. Bacteriological examinations of the water showed that it contained as high as 36,000 bacteria to the cubic centimeter. Typhoid germs were found in one examination, and the bacillus coli communis in every examination made. This experience has led the city of Ashland to construct a sand filtration plant.

A severe epidemic of typhoid fever occurred at Duluth, Minnesota, a few winters ago under conditions similar to those at Ashland.

We have noted the insanitary conditions at Chicago on a previous page. By way of illustrating the prevalence of typhoid in that city we may refer to the following table, showing the number of deaths from that disease in Chicago from January, 1890, to December, 1893, inclusive, taken from the annual reports of the Chicago department of health:

Number of deaths in Chicago resulting from typhoid fever.

Month.	1890.	1891.	1892.	1893.
January	53	67	311	41
February	136	61	187	30
March	103	71	76	41
April	45	136	56	58
May	32	408	70	56
June	107	167	55	60
July	86	200	211	55
August	115	182	179	76
September	85	198	138	86
October	72	171	92	81
November	67	150	67	43
December	47	186	47	43
Total	1,008	1,997	1,489	670

The above table shows that typhoid fever was epidemic in Chicago in February and March, 1890, in April, May, June, and July, 1891, and in January and February, 1892. All these outbreaks, as well as the general high typhoid death rate, must be attributed entirely to the polluted water supply. The next year, 1893, was the year of the Columbian Exposition, and much greater efforts were made in that year to insure proper sanitary conditions in Chicago. That these efforts were well directed is shown by the great reduction in the typhoid death rate for that year.

In regard to typhoid fever, it may be assumed as axiomatic that it is a disease of the fall months, which under normal conditions attains its maximum in October and November. If, then, we find it seriously prevalent during the winter months, we must assume the existence of unnatural—and as regards the cases just presented, unnecessary—conditions. So far as known, the reason for its excessive development in cold weather is the one already given. As to the validity of this reason, it may be pointed out that similar winter outbreaks have occurred at Zurich [1] and Geneva, Switzerland. The evidence is therefore now so far multiplied as to render it practically certain that a winter outbreak of typhoid fever means not only sewage contamination of the water supply, but the existence of conditions different from those ordinarily obtaining while the lakes are open. Hence the several outbreaks of winter typhoid, of which we have record in the Great Lake cities and towns are, aside from others, a valid reason why sewage treatment of some sort is rapidly becoming imperative at the Great Lake towns.

AMERICAN SEWAGE-DISPOSAL PLANTS.

MAINE.

Augusta, State Insane Asylum.—So far as known, the credit of the first attempt at sewage irrigation in the United States belongs to Mr. C. B. Laken, treasurer of the State Insane Asylum at Augusta, Maine, who carried out a system of irrigation there about 1872. From a description in the Seventh Annual Report of the State Board of Health of Massachusetts (1876), it is learned that the sewage, which then amounted to about 7,000 gallons per day, first passed by gravity into large tanks, where it was mixed with absorbents—straw, leaves, muck, etc. The solid parts were from time to time carted onto land, while the liquid portion flowed off, to be used for irrigation. In the summer of 1875 an irrigated area of a few acres yielded three crops of fine hay. A portion of the sewage was also used in irrigating a vegetable garden. It is understood that after the death of Mr. Laken this irrigation was abandoned.

NEW HAMPSHIRE.

Concord, State Insane Asylum.—The sewage of this asylum was used for irrigation about the same time as that of the Augusta asylum. In

[1] For an account of an outbreak of winter typhoid at Zurich, Switzerland, see Mr. Preller's paper on The Zurich water supply, etc.: Proc. Inst. Civ. Eng., Vol. CXI, pp. 257-295.

this case it was necessary to pump the sewage to the irrigated area. The Eighth Annual Report of the State Board of Health of Massachusetts states that, although the crops were very much increased in value, the sewage had not been disposed of at Concord in the systematic way which would be necessary in dealing with larger quantities. It is not known whether this irrigation is now in use or not.

Rockingham County Poor Farm.—A sewage-disposal plant was first operated at the Rockingham County Poor Farm in 1895. The plant, which is designed to meet the needs of about 1,000 people, consists of two sets of collecting tanks, with filter beds, all so arranged as to admit of intermittent use, the whole inclosed in a building. Sewage is first received in a collecting tank 7 feet wide, 9.5 feet long, and 7 feet deep, where most of the sludge is deposited. The sewage then passes into a second tank, about half the size of the first, and connected therewith at the bottom. The effluent from the second tank flows upon a filter bed of coarse sand, 22 or 23 feet square and 5 feet in depth. The sludge is utilized for compost. The filter areas are ventilated by a force draft over and under them. From the information at hand it is inferred that this plant is a patented process, owned by the Glover Sanitary Sewage Company.[1]

MASSACHUSETTS.

Amherst.—This is a college town in the Connecticut Valley, with a population in 1890 of 4,512. A public water supply was constructed in 1879 and sewerage and sewage-disposal works in 1881. The sewers are on the separate system. In the absence of a water course suitable to receive the sewage, it was conducted to a settling tank, from which the liquid matter is drained onto land through ditches, and the sludge is periodically removed and spread upon land. Ordinarily the sludge is removed once a week by simply opening a valve and allowing it to flow into a bed excavated in the sand, where the water rapidly drains away.

About three-fourths of the sewage of the town is treated in this way, the remainder going to a field having a sandy soil, where it flows into absorption ditches. Three heavy crops of hay are cut yearly from the irrigated area, which previously gave only one light crop a year. This tract is not underdrained, and it is stated that the sewage does not give any trouble by collecting in hollows. The field has a slight slope.[2]

Brockton.—A good recent example of intermittent filtration pure and simple may be seen in the works recently constructed at Brockton, Massachusetts, a shoe-manufacturing town a short distance southwest of Boston, with a population in 1890 of 27,294. Waterworks were completed in 1880 and 1881, but a separate system of sanitary sewers was not put in operation until the latter part of 1894.

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[1] Refer to Eng. and Bldg. Record, Vol. XXXIII, May 9, 1896.

[2] Refer to Twenty-fifth Ann. Rept. Mass. St. Bd. Health; Sewage Disposal in the United States; and Eng. News, Vol. XXVIII, July 21, 1892.

A

B

BROCKTON MASSACHUSETTS. FILTRATION FIELDS.

A. Turnips and sweet corn, *B*. Pease, sweet corn, and beans.

By the application of meters the use of water at Brockton has been kept quite low. For the year ending November 30, 1894, the average daily consumption per capita was only 24.3 gallons, the highest figure being 39.4, for the month of June, and the lowest 18.7 gallons, for March. In the design of the sewers Mr. Snow, the city engineer, has made allowance for a daily consumption of 60 gallons per capita, as well as for a possible leakage by infiltration into the sewers. The main outlet sewer leading into the receiving reservoir is of brick, egg-shaped, varying from 26 by 39 inches to 22 by 48 inches in size, and about 2 miles long. The leakage by infiltration into the outlet sewer is estimated at about 120,000 gallons per day ordinarily, and in flood time at probably 350,000 gallons.

Inasmuch as there was no area available on which sewage could be delivered by gravity, it was necessary to raise the sewage to the filtration area by pumping. The force main provided for this purpose is of 24-inch cast iron, 16,640 feet in length, and rises 34.5 feet from the pump to the terminal chamber.

The filter area comprises some 30 acres, laid out in 23 beds. The soil of this area is mostly sand for the depth of several feet, but varies considerably in its mechanical constituents. In constructing the beds the natural material was not disturbed except at the surface; on 12 of them the sand was stripped from the subsoil; on 5, a thin layer of subsoil has been allowed to remain, and 6 of the beds have surfaces partly of the top sand and partly of subsoil. The general method of constructing these filter areas is the same as that followed elsewhere, and need not be especially referred to at length. The cost of the disposal works at Brockton is stated at $209,772, of which $59,536 was for the disposal area proper. The main items in the cost of the disposal area are 3,046 square yards of grubbing at $2 per yard, amounting to $6,092; 85,830 cubic yards of excavation in the filter beds, at 23 cents per yard, costing $19,739; trenching for and laying sewage-distributing pipes and underdrains, $12,631; land damages, $9,234. The balance of the $59,536 is made up of miscellaneous small items.

The experience with the sewage beds at Brockton has indicated that furrowed beds are far preferable for winter disposal to flat beds. During the winter of 1894 several of the beds were left with level surfaces, but the surface froze to such an extent on these as to prevent the sewage from penetrating them, whereas beds which had been furrowed the preceding fall took sewage readily during the entire winter. Accordingly, in the winter of 1895–96 all the beds in use were furrowed and no trouble was experienced during that season from freezing. The following, from the reports of the city engineer of Brockton, gives the average amount of sewage disposed of from month to month and its temperature as it reaches the beds.

Average amount and temperature of sewage received at Brockton sewage-disposal works.

Month.	Gallons per day.		Temperature.	
	1895.	1896.	1895.	1896.
			° F.	° F.
January	215,000	474,000	42.6	43.5
February	109,000	568,400	40.6	42.6
March	142,000	648,500	39.5	42.4
April	250,000	475,100	42.3	45.0
May	338,000	321,900	53.5	52.1
June	228,000	381,700	60.1	56.3
July	195,000	322,800	60.8	59.9
August	273,000	365,900	64.0	62.2
September	275,000	527,100	64.0	61.0
October	488,000	600,100	57.0	57.4
November	474,000	616,000	51.0	54.1
December	525,000	599,000	48.0	49.9

According to the report of the Massachusetts State board of health for 1895, the chemical analysis of the sewage and effluent from the underdrains at Brockton, made February 12, 1895, resulted as follows: Of the sewage, the total residue amounted to 84.4 parts per 100,000, of which 40.2 parts were dissolved and 44.2 parts suspended; the total loss on ignition was 38 parts, 12.4 dissolved and 25.6 in suspension; the free ammonia amounted to 3.46 parts per 100,000; the total albuminoid ammonia to 0.91 part, of which 0.244 was dissolved and 0.066 part in suspension; chloride amounted to 9.05 parts; nitrogen, as nitrates and nitrites, nil; the oxygen consumed in an unfiltered sample was 8.56 parts per 100,000, and in the filtered sample 3.12 parts per 100,000; the iron present in an unfiltered sample was 0.32 part, and in a filtered sample 0.08 part per 100,000. The hardness was 6.4.

The effluent of the same date showed an entire absence of turbidity and sediment, while the sewage was thick and contained a heavy black sediment. On Nessler's scale the colors showed 0.01; the residue on evaporation was 4 parts per 100,000; free ammonia, 0.0248 part; albuminoid ammonia, 0.0038; chlorine, 0.75 part; nitrogen as nitrates, 0.045 part; nitrites, nil; the oxygen consumed amounted to 0.024 part per 100,000; hardness, 0.6; and iron entirely absent. In regard to this effluent, it is proper to remark that it is stated to contain a large amount of ground water.

The design at Brockton includes a number of refinements, such as automatic arrangements for gaging the flow of sewage, which are very creditable to the city engineer, Mr. Snow, as well as to the municipal authorities of Brockton in general. Considering the scientific way in which the work there has been started, there is no reason why the

degree of purification to be attained should not be very high, especially since the works are to be operated as intermittent filtration areas only, and we may hope in the future to obtain from Brockton further information of value and interest to all concerned in works of sewage disposal.

During the year 1896, notwithstanding the additional cost of considerable experimental work, the total cost of labor at disposal works was only $2,195.21, or at the rate of $12 per million gallons of sewage treated. This sum included several items, such as setting of trees, grading about building, and pipe testing, which were in the nature of permanent improvements. Labor expended on surface of beds amounted to $932.03; for tending gates, $254.98; and for removing snow, $51.04; a miscellaneous item of $295.40, and a few others making up the remainder. Probably where these works are more fully established the cost of a treatment which yields a very fair effluent will not exceed $7 or $8 per million gallons treated; or, taking into account the value of the crops raised, the works will be about self-sustaining.

In his annual report for 1896 Mr. Snow has given a considerable amount of interesting information as to the operation of the Brockton plant. From this report it is learned that a variety of crops was planted on the beds receiving both sewage and sludge, such as pease, beans, tomatoes, sweet corn, cabbages, and turnips. Some of the conclusions derived from last year's experience are as follows: Pease and beans it is considered will do best if planted on level beds rather than on mounds. The pea crop last year was successful, one of the leading hotels of Brockton taking the entire product. Beans are stated to have failed. Sweet corn, which takes a large amount of sewage and demands but little attention, should be planted 4 feet between rows and in hills 3 feet apart in the rows. Cabbage requires more care than sweet corn, and when sludge is applied to the surface of the bed the same must be irrigated as though the bed were not cropped. It is considered that on a coarse sand or gravel soil with a level surface turnips should receive large doses of sewage, while with heavier soil small doses and a ridged surface will give the best results. Turnips appear to require considerable moisture during the first growth and but little after the root is formed. Six beds were planted with field corn on May 10. The crop was cultivated on June 1, and again about July 1, with a horse hoe. All the beds did well, the yield of one amounting to 144 bushels of ears per acre, or about 70 bushels of shelled corn.[1]

Gardner.—This place is a manufacturing town, situated in the central part of the State, on a divide between the Connecticut and Merrimac rivers. The population in 1890 was 8,424. A sewage-disposal plant by intermittent filtration was constructed in 1891, in conformity with plans approved by the Massachusetts State board of health. This board

[1] Refer to Ann. Repts. of City Eng. of Brockton; Repts. Mass. St. Bd. of Health; and various articles in Eng. News.

required sewage purification at Gardner, because turning sewage into the only available water course would probably create a nuisance. The tract purchased by the town for the disposal area contained about 17 acres of sand and gravelly soil. Much of the material is too fine for efficient filtration. This was overcome by making filter beds largely artificial, they being formed of selected porous sand and gravel from the material. At present there are twelve thoroughly underdrained filter beds, with a total area of 1.04 acres, two supplementary beds not underdrained and with a total area of 0.37 acre, also two other small underdrained beds, containing altogether 0.14 acre. One of the small beds is used to receive sludge from the sludge tank.

The filter beds at Gardner are smaller than those used at Marlboro, Framingham, and other places in Massachusetts, described further on. The sewage is delivered upon the beds by troughs, and each bed is provided with an overflow to prevent washing away the banks in case the sewage should at any time rise too high.

The results obtained at Gardner are said to be satisfactory in summer, but in winter the area is too small for efficient filtration, a difficulty which can be remedied by providing a larger area. The sewage reaches the filter area during the winter at a temperature not much above 40° F.

The cost of preparing beds with piping was about 12 cents per square foot of area. The total cost, including tanks and accessories, was about 14 cents per square foot of filter areas.[1]

Greenfield.—This place had a population in 1890 of 5,252. Sewage has been used for irrigation upon a meadow owned by a private party since 1882. As originally designed, the sewage was systematically distributed over the meadow, but during the last few years, since the death of the former owner, apparently but little effort at such distribution has been made. In consequence, recent statements at hand indicate that the sewage has caused a nuisance.

Lenox.—This place had a population in 1890 of 2,889. A combined system of subsurface and surface irrigation, preceded by tank sedimentation, was adopted in 1876, at which time the population was probably somewhat less than 2,000. The total area originally employed was only about 1½ acres. In October, 1888, a new subsurface-disposal area was placed in operation, which, however, did not cover the whole 17 acres purchased. As to recent results no information is at hand. Lenox enjoys the distinction of being the first town in Massachusetts to construct sewage-disposal works.[2]

Marlboro.—Population in 1890, 13,805. The city is situated on the dividing ridge between the Sudbury and Assabet rivers. The greater part of the drainage, however, naturally flows into Sudbury River,

[1] Refer to Twenty-fourth Ann. Rept. Mass. St. Bd. Health, 1892; Sewage Disposal in the United States, 1894; and Eng. News, Vol. XXIX, Feb. 16, 1893.

[2] Refer to Twenty-fifth Ann. Rept. Mass. St. Bd. Health; Sewage Disposal in the United States; and Eng. News, Vol. XXVIII, July 14 and 21, 1892.

from which Boston takes a portion of its water supply. The city of Boston, therefore, had a direct interest in so disposing of the Marlboro sewage as to leave the Sudbury River unpolluted, and, after some negotiations, agreed to pay $62,000 toward constructing the sewage-disposal plant. The sewage flows to the disposal fields by gravity. The total area purchased by the city is 62 acres, upon which forty-four beds for the filtration of sewage and six similar beds for sludge disposal, all covering with their dividing embankments a total area of about 37 acres, have been laid out. Thus far four sludge beds and thirteen sewage beds, or a total of about 11.3 acres, have been prepared for use. The material, which is for the most part a somewhat fine, porous sand with an effective size of 0.12 to 0.14 millimeter, has been thoroughly underdrained by means of parallel lines of 4-inch pipes laid with open joints 50 feet apart and about 6 feet beneath the surface. Filter beds were prepared for use by the removal of the top loam and the leveling of the surface of each at a convenient elevation.

The principal industry at Marlboro is the manufacture of boots and shoes; and, aside from the wastes of the manufacturing establishments, the sewage is ordinary city sewage, varying in strength with the amount of ground water entering the sewers, which were constructed on the separate system. No underdrains were laid beneath the sewers, and during wet seasons a large amount of ground water gains access to them through the joints. The total length of sewers laid to the end of 1895 was a trifle over 22 miles. The amount of sewage is not definitely known. A measurement on May 12, 1892, indicated about 30,000 gallons per day; on May 25, 1892, after heavy rains, the flow was 790,000 gallons per day. No attempt has thus far been made to raise crops on the filter areas.

The results obtained in purification have been satisfactory; over 95 per cent of the organic matter, as represented by the albuminoid ammonia, having been removed. The winter temperature of the sewage as it reaches the fields is from 39° to 42° F. The winter experience indicates that the beds work much better when ridged—as seen in Pl. IV, showing the filter areas at Pawtucket, Rhode Island—than when left level.

It has not been the custom to employ a man constantly in caring for the sewage disposal, but only from time to time as required to change the flow of sewage and to remove scum from the surface of the beds, etc., payment being made by the hour for the time actually consumed. The cost of all work on account of the disposal plant during the year 1893 amounted to $497.19. There seems to be no doubt, therefore, if the amount of labor was sufficient, that the town could recoup itself for the expenditure by preparing more beds and raising crops thereon.[1]

[1] Refer to Twenty-fourth, Twenty-fifth, and Twenty-seventh Ann. Repts. Mass. St. Bd. Health; Sewage Disposal in the United States; and Eng. News, Vol. XXVIII, Aug. 25, 1892.

Concord, Massachusetts Reformatory.—The sewage of this institution was originally discharged into the Assabet River at a point near the institution, but in 1883 an act was passed by the Massachusetts legisture authorizing an expenditure of a sum not exceeding $5,000 for the disposal of the sewage by some other method. The plans adopted include arrangements for pumping the sewage upon an adjacent field, where it is used in broad irrigation of grass and corn crops, as well as other tilled crops to some extent. The soil of this field is light, free, and sandy, with the ground water at a considerable depth below the surface. Portable troughs are used for distributing the sewage to different parts of the field.

The labor is all done by convicts. Assuming a fair valuation for the labor actually used under normal conditions of employment, we have the following as the approximate annual cost of operation: 55 tons soft coal, at $4, $220; salary of attendant, $600; repairs and sundries, $80; total, $900.[1]

Medfield.—Population in 1890, 1,493. Sewers and sewage-disposal works were constructed in 1886, the sewage disposal including preliminary sedimentation and upward filtration through excelsior supplemented by intermittent filtration through natural soil. The material of the filter area is mostly coarse gravel, with ground water about 10 feet below the surfaces of the beds, which are underdrained. There are four beds which, as a general rule, take the sewage in turn for two days. The filter area consists of 1 acre of ground, graded nearly level. The entire cost of the disposal works, including cesspool, pipe from cesspool to outlet, earthwork, engineering, superintendence, and profit to contractor, was about $1,000. The annual expense of maintenance is stated at about $30 a year, the labor being chiefly to change regularly the gate whereby the sewage is diverted from one portion of the filtration area to another.

Analyses of the effluent from the Medfield area, made in October, 1893, showed that the quality was still quite as good as indicated by analyses made when the works were first operated in 1887.[2]

Mystic Valley.—These works, which are operated by chemical precipitation purely, were constructed in 1887 and 1888 by the city of Boston in order to protect the Upper Mystic Lake, whence the water supplies of the Charlestown district of the city of Boston and of the towns of Chelsea, Everett, and Somerville are derived.

Near the head of Upper Mystic Lake, in Winchester and Woburn, there are about a dozen tanneries, the drainage from which formerly passed directly into the lake, which was also considerably polluted by house drainage flowing into the Abbajona River, the influent stream of Mystic Lake. In 1878 a sewer was constructed intercepting all this objectionable drainage and delivering it into Lower Mystic Lake, which

[1] Refer to Seventh Ann. Rept. Mass. St. Bd. of Health, Lunacy, and Charity, Supplement, 1886.

[2] Refer to Nineteenth Ann. Rept. Mass. St. Bd. Health; Jour. Assoc. Eng. Socs., Vol. VII, July, 1888; and Eng. and Bldg. Recd., Vol. XVIII, 1888.

is subject to tidal action. Its delivery there, however, led to controversies between the adjoining towns and the city of Boston, which were finally settled by the construction of the Mystic Valley Chemical Purification Works. Inasmuch as the chief object of these works was to purify manufacturing wastes, they may easily be placed first among successful works of this character. A general view of the works is given in fig. 1 of Water-Supply and Irrigation Paper No. 3.

The works consist in detail of a pump well, connected with the main sewer by a branch sewer of brick, a sewage pump and engine, engine house, four settling tanks, a sludge well, sludge pump, and a series of settling basins for receiving the sludge. In the engine house there are three vats so arranged that the precipitant is fed from the middle vat, which is placed lower than the other two, in which the precipitant is dissolved. These vats are provided with steam coils for heating the water used and with a stirring apparatus driven by the engine. The precipitant is fed to the sewage as it flows from the branch sewer into the pump well, where the process of pumping thoroughly incorporates the chemicals. From the pump the sewage passes into the settling tanks. It is then allowed to remain quiescent for about three hours, when it is found that the sedimentation process is complete. The clarified effluent is then drawn off by removing stop planks. The sludge is pumped, as necessary, into a flume which conveys it to the sludge basins shown in fig. 1 of Water-Supply and Irrigation Paper No. 3.

The cost of the works, including the preparation of the sludge basins, was $10,410.

For the thirteen months ending January 31, 1892, the total quantity of sewage pumped and treated was 133,102,028 gallons. Sulphate of alumina is used as the precipitant, and during this period the total quantity consumed was 331,890 pounds; the amount of coal, 210.7 tons. The quantity of sludge removed during the same period was 2,334 cubic yards, which was mostly carted away by a neighboring farmer for fertilizer. The rate of application of participant was 1 part to 3,354 parts of sewage or 1.24 net tons per 1,000,000 gallons of sewage.

The operation of this plant by the city of Boston ended July 18, 1895, at which time the Metropolitan Sewage Commission assumed control of it. From January 1 to July 18, 1895, the average daily amount of sewage pumped and treated was 376,400 gallons, requiring 143,540 pounds of sulphate of alumina. The Metropolitan Commission has made the Mystic Valley sewer a part of the Metropolitan sewerage system and discontinued the chemical treatment. The first annual report of the Metropolitan water commissioner for the year ending January 31, 1896, states that this plant required the service of about 14 men to operate it, and that its discontinuance removes an annual expense of about $20,000.[1]

[1] Refer to annual reports Boston Waterworks; First Ann. Rept. Met. Water Com.; Sewage Disposal in the United States; a paper by W. F. Larned in Jour. Assoc. Eng. Socs. for June, 1888; and Eng. and Bldg. Recd., Vol. XIX, 1889.

Natick.—Natick is about 17 miles from Boston, on the Boston and Albany Railroad, and had in 1890 a population of 9,118. A public water supply has been in use since 1874. In 1885 Eliot C. Clark, engineer to the Massachusetts drainage commission, recommended that a joint sewage-disposal system be built for the towns of Natick, Framingham, and Ashland, and for the Sherborn Prison, situated a short distance from South Framingham, the principal village in Framingham town, with disposal on a gravelly and sandy area, which has since been selected by Framingham and Natick for this purpose. Mr. Clark's idea was that these several towns and the public institution should act in concert, but, unfortunately, the difficulty of reconciling local differences prevented the adoption of his scheme. The two towns of Framingham and Natick have, however, acted separately in utilizing the area selected by Mr. Clark. Framingham completed its sewerage and sewage-disposal system in 1889, while the Natick system was put in operation only during the year 1896.

The indifference of Natick as to sewage purification has been for a number of years particularly flagrant by reason of the flow of a considerable portion of the town sewage into Pegan Brook, a tributary of Lake Cochituate, one of the main sources of the Boston water supply. Negotiations have been had between the city of Boston and Natick looking to purification of this sewage, but without effect. Finally, a few years ago, the city of Boston constructed, at its own expense, on a sandy plateau adjacent to the lake, a filter area upon which the ordinary flow of Pegan Brook was diverted and purified by intermittent filtration. Some portion of the flood flow of the brook has, however, necessarily gone into the lake whenever heavy rains occurred.

The construction of the Natick works began in 1895, under the direction of Samuel M. Gray as engineer. The detailed plans prepared by him provide for bringing the sewage by gravity to a pumping station through a 30-inch circular brick sewer and 24-inch cast-iron pipe with lead joints. The 24-inch pipe is used where the main sewer passes near the head of Lake Cochituate, in order to prevent any possible leakage into that body of water.

The pumping station is provided with a screen chamber, receiving gallery, storage reservoir, pump wells, etc., and the usual accessories of such a plant. According to a statement made by Mr. Gray, when the sewage reaches the screen chamber it passes through iron bars placed three-quarters of an inch apart, after which it may be turned, as desired, either into reservoirs for storage or into a pump well, from which it may be raised directly to the filter areas. In this latter arrangement the pump can be regulated to take the flow as it comes, thereby saving the lift which would otherwise be necessary if it went to the reservoir. The total capacity of the reservoir is 500,000 gallons. The intention is that the night and Sunday flow be stored in the reservoir.

The sewage is delivered to the filter areas through 8,000 feet of 16-inch cast-iron force main, laid on a grade throughout its entire length, for the purpose of permitting the contents to flow entirely back into the pump well in case it becomes necessary to clean the interior surface of this pipe.

The tract of land appropriated for the disposal works was originally covered with a small growth of wood brush. The soil is sandy and generally well adapted to filtration, although there are thin layers of sandy clay in some of the beds which, as Mr. Gray believes, will make it necessary to lay underdrains. The effluent from the underdrains will be discharged into a small stream which enters the Sudbury River below the outlet of Lake Cochituate. It will be noticed, therefore, that the sewage, as well as the effluent, is entirely diverted from Lake Cochituate, in the same way as in the neighboring town of Framingham.

The entire plant as designed includes the preparation of 12 acres of filters to be underdrained with 3-inch tile, laid on a grade of 2 feet in a hundred, in lines 36 feet apart. The work in 1895 included the preparation of 2 filter beds of 1 acre each, from which the underdrains were omitted. Another bed was completed in 1896 with underdrains.[1]

Norfolk County Jail.—This institution has a land disposal plant of some sort, particulars of which, however, are not at hand.

North Brookfield.—The village of North Brookfield is situated in the town of Spencer, in which a water supply was introduced in 1883. The population of the whole town in 1890 was 8,747, having increased from 7,466 in 1880. North Brookfield proper, however, has a population of only about 3,000, which can be ultimately connected with the main sewer as built in 1893, when sewage-disposal works were also built, the system adopted being that of broad irrigation. According to a statement of Mr. Craig, the supervising engineer of the work, published in the Engineering News of March 22, 1894, it would appear that there are about 20 acres of a farm owned by the town which is well adapted to broad irrigation, the soil being naturally very light and dry, and not yielding heavy crops under ordinary methods of farming. In order to reach the highest point of this area it was necessary to employ an inverted siphon about 1,600 feet in length, which has been successfully constructed and operated, and a profile of which may be seen in Engineering News at the place indicated.

This sewage farm was first in working order in November, 1893, and no statements as to the results of broad irrigation are yet at hand. It is considered, however, that with the favorable soil of the locality very satisfactory results may be attained. This farm is also interesting as being very inexpensive, the total cost of the entire system of sewers, including flush tanks, screen chamber, and labor necessary in preparing the farm, being only $9,700. The sewage is first received in a storage tank, from which it is discharged intermittently to the farm.

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[1] Refer to Eng. News, Vol. XXXV, June 4, 1896.

Pegan Brook.—Some general statements in regard to the filter areas constructed for the purpose of excluding from Lake Cochituate the raw sewage of Natick, which previous to the construction of the Natick sewage-disposal works flowed into Pegan Brook and thence directly into the lake, have been made in discussing Natick (pp. 50–51), and a few detailed statements may now be added. The filter areas are three in number, constructed by removing the soil and placing it in embankments 5 feet high around and between the beds. The filter material, to the depth of 8 feet, is mostly sand, about as fine as ordinary plaster sand. The three beds are about 2, 0.75, and 1.25 acres, respectively. Their elevations are 140, 144, and 146.8 feet above the waterworks datum, 134.4 feet being the elevation of low water in the lake. The lowest bed, with an area of about 2 acres, is not underdrained. Water percolates freely through the sand, which is stated to be excellent filter material. Underdrains about 100 feet apart and 8 feet deep are laid beneath the upper beds. They consist of 8-inch vitrified tile pipe, laid with open joints wrapped with canvas. The underdrains were chiefly designed in order that samples of the effluent may be obtained for examination. An earth dam for diverting the water of the brook onto the filter beds and a pumping plant were included in the plans. The entire cost is stated at $12,585.11.

The Pegan Brook filters are of special interest, because, so far as known, they are the first filter areas ever constructed for the filtration of a polluted feeder to a natural lake which is the source of a public water supply. There may possibly be some such arrangement in use abroad, but certainly this is the first plant constructed for such purpose in the United States.[1]

Waltham, School for the Feeble-Minded.—An intermittent subsurface irrigation or filtration plant was constructed at this State institution about 1890. In 1893 permission was granted to connect the sewers of the school with the sewerage system of the city of Waltham, since which time it is understood that the disposal area has been out of service.

Sherborn Prison.—A number of years ago arrangements were made for disposing of the sewage of this State institution by subsurface irrigation. Information as to the extent and success of the project is not at hand. The works are believed to be out of use.

South Framingham.—The sewage-disposal works at South Framingham, Massachusetts, are of considerable interest as involving both broad irrigation and intermittent filtration, and also because real progress has been made here in raising crops on filter beds. Unfortunately, at South Framingham, as well as at about all the other sewage farms in the United States, no one has yet attempted to keep statistics as to the daily flow of sewage, the amount applied, and other important facts, data which must be at hand before definite conclusions can be

[1] Refer to Ann. Rept. Boston Waterworks for 1893, and Eng. and Bldg. Record, Vol. XXIX, Apr. 1894.

A

B

SOUTH FRAMINGHAM, MASSACHUSETTS, SEWAGE FARM

A, Sewage inlet to filter (field of growing corn in left foreground, larger corn in distance). *B* Portion of cabbage field.

drawn as to the efficiency of the process at any given point. In favor of South Framingham it may be said that the cropping on the filter beds has been very successful, but as the results have been referred to on page 43 of Water-Supply and Sewage Irrigation Paper No. 3, a further account here is unnecessary.[1]

Wellesley College.—Previous to 1892 the sewage was mostly disposed of by passing it through small and imperfect artificial filters of peat and gravel, but, as the results were unsatisfactory, new works were constructed in that year for treatment by intermittent filtration. Additions to the works were made in 1893. The sewage to be treated is that of about 500 persons, for which purpose a filtration area of 1.55 acres has been provided.[2]

Westboro.—Population in 1890, 5,195. Construction of a sewerage system began in 1891. About 33 acres of land located on the right bank of the Assabet River have been acquired by the town for sewage-disposal purposes, nearly one-half of which may be classed as either swamp or meadow, subject to flooding at times of high water. The sewage is conducted to a settling tank on the disposal area, built in two compartments, with a total capacity of less than 1,000 gallons. Two filter beds, with a total area of a little over 2 acres, were prepared in 1892 by stripping off most of the loam and filling with coarse gravel, the material beneath being a fine compact sand nearly impervious to water. The information at hand indicates that this plant has not worked well.[2]

Worcester.—To show the relative degree of purification obtained by chemical processes of treatment in comparison with intermittent filtration and irrigation processes, brief reference may be made to the results obtained by the works at Worcester, Massachusetts, which may be considered not only the best example of a chemical-purification plant on a large scale thus far completed in the United States, but which, in the opinion of those competent to judge, is as good an example of this method of purification as can be found anywhere. The fact that it has not been successful in entirely mitigating the pollution of the Blackstone River, into which the effluent from the Worcester works flows, must be attributed to inherent difficulties of the chemical process, and not to any lack of proper application of that process at Worcester. Indeed, the author takes pleasure in saying that after having examined the large purification works abroad, as well as a greater portion of those in this country, he has nowhere seen a better example of the chemical treatment, pure and simple, than that at Worcester.

According to the report of the superintendent of sewers for the year 1895, it appears that in 1894, as an average, these works removed 49.35 per cent of the total amount of organic matter present in the sewage as determined by evaporation; of the amount in suspension, 94.45 per

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[1] Refer to Report of Com. on Drain. and Sew., etc., Nov., 1889; several articles in Eng. News; and Sewage Disposal in the United States.

[2] Refer to Twenty-fifth Ann. Rept. Mass. St. Bd. Health, 1893.

cent was removed; of the total amount, based on the albuminoid ammonia, 50.79 per cent was removed; of the amount in suspension, based on the albuminoid ammonia, 89.54 per cent was removed; the total amount by oxygen consumed was 43.84 per cent, and the amount in suspension by oxygen consumed 81.08 per cent.

Experience at Worcester indicates that different percentages were removed in the various seasons, as, for instance, in 1894 the total per cent of organic matter removed from the sewage as an average, from July to December, was, by evaporation, 55.02 per cent; the amount in suspension, also by evaporation, 95.76 per cent; the total amount of albuminoid ammonia, 53.78 per cent; the total amount by suspension in albuminoid ammonia, 94.36; total amount by oxygen consumed, 50.23 per cent; the amount in suspension by oxygen consumed, 92.42 per cent.

From December to July the total amount of organic matter removed by evaporation was 42.76 per cent; amount in suspension, 93.08; total amount by albuminoid ammonia, 46.63 per cent; amount in suspension by albuminoid ammonia, 83.26; total amount by oxygen consumed, 37.11; amount in suspension by oxygen consumed, 89.27 per cent.

The average analyses of the sewage for the year ending December 1, 1895, were as follows: Free ammonia, 1.16 parts per 100,000; total albuminoid ammonia, 0.518 part; dissolved albuminoid ammonia, 0.249 part; suspended, 0.270 part. The oxygen consumed in unfiltered sewage was 5.27 parts and in filtered sewage 2.91 parts per 100,000, and the chlorine, 5.98 parts. The average of the effluent for the same year was: Free ammonia, 1.008 parts; total albuminoid ammonia, 0.252 part, of which 0.228 part was dissolved, 0.024 part suspended. In unfiltered effluent the oxygen consumed amounted to 2.4 parts and in filtered effluent 2.27 parts, and the chlorine to 5.92 parts per 100,000. Taking the purification by percentage actually removed, we have, for the free ammonia, 13.02 per cent; total albuminoid ammonia, 51.63 per cent; dissolved albuminoid ammonia, 8.43 per cent; suspended albuminoid ammonia, 91.11 per cent; oxygen consumed, total, 54.35; in solution, 21.99; chlorine, 1.05 per cent. It will be noticed that the chemical process only moderately touches the free ammonia and the dissolved albuminoid ammonia.

The works at Worcester were constructed chiefly because of serious complaints on the Blackstone River as to the pollution caused by the Worcester sewage, which originally flowed into the stream in a raw state. The following gives the mean of a series of analyses of the stream as made by the Massachusetts State board of health in 1895: Color on Nessler's scale, 0.71 part per 100,000; total residue on evaporation, 22.15; loss on ignition, 5.18; free ammonia, 0.3246 part per 100,000; total albuminoid ammonia, 0.0898 part, of which 0.0597 part was dissolved and 0.0301 part was suspended; chlorine, 1.86 parts; nitrogen as nitrates, 0.0267 part; nitrogen as nitrites, 0.0063 part; hardness, 7.3.

A

B

WORKS AT WORCESTER, MASSACHUSETTS.

A, General view of precipitation tanks; *B*, Another view of precipitation tanks.

In considering these results it should be remembered that the sewerage system of the city of Worcester is a combined system, and that frequently at the time of heavy rains a considerable portion of the sewage flows into the Blackstone River entirely without treatment. The information in regard to the Worcester works is too extensive to be given in detail here. It may be found in the several annual reports of the city engineer and the superintendent of sewers of the city of Worcester, and also in the reports of the Massachusetts State board of health.

The litigation between the city of Worcester and the town of Millbury, a few miles down the river, on account of the pollution of the Blackstone River, may, however, be briefly mentioned by reason of its being the most extensive of legal proceedings involving stream pollution thus far taken in the United States. Without detailing all the steps, it may be stated that the objections of Millbury finally resulted in the passage of a mandatory act of the Massachusetts legislature requiring Worcester to purify its sewage before allowing it to flow into the Blackstone River. Under the provisions of this act the purification works were built and first operated in 1890.

In 1890 the population of Worcester was 84,655, while in 1895 it had increased to 98,678, and at the same time the pollution of the river was so bad that in the latter year Millbury again brought suit against Worcester. At the trial, in April, 1896, the case of the town of Millbury was supported by Allen Hazen, Col. George E. Waring, jr., Rudolph Hering, Mrs. Ellen H. Richards, and George W. Rafter, while Worcester's side was represented by Samuel M. Gray, Prof. William T. Sedgwick, Prof. H. P. Kinnicut, Charles A. Allen, Harrison P. Eddy, and F. A. McClure. The testimony touched nearly every phase of sewage purification and stream pollution. In a decree dated December 14, 1896, the presiding justice ordered that within three months Worcester should take steps to purify the stream. The preliminary steps to comply with this decree have been taken.

Worcester Insane Hospital.—These works were constructed in 1876, and have since successfully disposed of the sewage of about 600 people, the ordinary population of the hospital.

As shown on a previous page, some attempt has been made to dispose of sewage by broad irrigation at the State insane hospitals at Augusta, Maine, and Concord, New Hampshire, a short time before the sewage farm of the Worcester Insane Hospital was first operated. Neither, however, was entirely successful, and both have been abandoned. We must therefore give the credit to the authorities of the Worcester Hospital for instituting the first permanently successful sewage-irrigation farm in the United States.

The hospital building is situated on a considerable rise of ground, about 3,000 feet west of the main irrigation field, which includes 14 acres. There are also arrangements for drawing sewage along the line of the sewer leading from the hospital to the main field, which permits

the irrigation of a total of from 30 to 40 acres. The entire hospital farm includes 257 acres.

The work was mostly constructed by the inmates of the hospital and no statement of cost can be made.[1]

PLANTS PROJECTED IN MASSACHUSETTS.

Information as to the number of projected sewage-purification plants in Massachusetts has been obtained from the annual reports of the State board of health, 1890 to 1895, inclusive, as follows:

Andover.—This town submitted plans for sewage disposal to the State board of health for approval in 1895. The plans proposed were rejected as thoroughly impracticable, and the sewer commissioners were instructed in a communication dated October 10, 1895, as to the proper lines on which to develop sewage purification for that place.

Braintree.—The sewerage committee of this town submitted plans for sewage disposal to the State board of health in 1893. In its answer, under date of July 6, 1893, the board suggested that inasmuch as the towns of Braintree and Weymouth were contiguous and were near the sea, the interests of both communities might be served by united action in the construction of an outlet to tide water.

Concord.—The committee on sewage of this town asked the advice of the State board of health on a proposed plan of sewage disposal in 1894. Under date of January 3, 1895, the board replied that, judging from the outline presented, the plan proposed could be commended as well adapted to the needs of the town, and that a system of intermittent filtration on the area proposed would be a proper method of disposing of the sewage of Concord.

Danvers.—In 1895 the board of health of this town applied to the State board for advice as to the disposal of sewage of three morocco factories in that place. In its answer, under date of December 5, 1895, the State board of health suggested, as a line of investigation, that probably the sewage should be first conducted into large settling tanks, where the sludge would deposit, and from which the liquid could be pumped to a filter bed and the sludge be frequently removed from the tanks, to be disposed of presumably either by burying or for use as manure in agriculture.

Foxboro Hospital for Dipsomaniacs and Inebriates.—Information as to an intermittent filtration plant proposed for this State institution may be found in the Twenty-third and Twenty-fourth Annual Reports of the Massachusetts State Board of Health.

Leicester.—Plans for sewage disposal for this town were submitted to the State board of health in June, 1893. They included preliminary sedimentation and filtration, the sludge to be allowed to drain out in beds, after which it will be carted away for use in agriculture.

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[1] Refer to the Forty-seventh Ann. Rept. of the Trustees of the Hospital for the year ending September 30, 1879.

Medfield Insane Asylum.—Plans for the disposal of the sewage of this State institution by means of intermittent filtration were submitted to the State board of health in 1892.

Pittsfield.—Chapter 357 of the acts of 1890 authorizes the city of Pittsfield to build a system of sewerage and sewage disposal, subject to the approval of the State board of health. The plans were presented to the board for its approval in 1891. They provide for the permanent disposal of the sewage by intermittent filtration, but permit a temporary discharge into the Housatonic River until June 1, 1900, after which date the sewage of the city must be treated before discharge, as provided in the plans.

Spencer.—This town was advised by the State board of health, under date of December 8, 1893, as to proper disposal of the town sewage by land treatment. The board pointed out that the wastes from the gas works which now enter the sewers of Spencer should be either excluded or so treated before admission as to remove all tarry or oily substances which would tend to clog the filters.

Bridgewater, State farm.—Under date of December 14, 1895, the State board of health advised the superintendent of the State farm at Bridgewater as to the purification of the sewage by land treatment, preferably by filtration through porous soil about 1¼ miles from the building.

Tewksbury.—The State board of health advised the authorities of this town in regard to land purification of the sewage under date of October 3, 1895.

Wakefield.—In 1892 the sewerage committee of Wakefield submitted to the State board of health plans for the sewerage and sewage disposal of the town, the sewage of the principal village of the town to be treated by filtration upon land, and the remainder of the sewage to be discharged into the main metropolitan sewer. In its answer to the application, under date of October 7, 1892, the State board of health gives general suggestions as to the best method of preparing the disposal areas.

At several other places in Massachusetts sewage-disposal works have been projected and are likely to be constructed in the next few years. The foregoing examples are sufficient to indicate the advanced state of sewage-purification questions in the Commonwealth of Massachusetts.

RHODE ISLAND.

Sewage-disposal works have been either constructed or projected in Rhode Island as follows:

Central Falls.—The present city of Central Falls was part of the old town of Lincoln, in Providence County. The population of the town of Lincoln for 1890 is given at 20,355. In 1892 a tract of land of about 35 acres was purchased for the disposal of the sewage of the western district of the city, at a cost of $20,000. The disposal plant, which for the present includes three filter beds of about one-fifth of an acre each,

was constructed in 1896. Additional filter areas are to be constructed as required. The sewage flows to the disposal grounds by gravity. The cost of the work of preparation to date, including settling tank, is is about $9,500.[1]

Pawtucket.—Pawtucket, with a population of 32,577, according to the State census of 1895, is divided into two principal drainage districts, known as the Blackstone River district and the Moshassuck River district. The sewers of both the districts are of the combined system, those of the first district amounting to 27.16 miles, and those of the second district to 7 miles. The filter plant is connected with the sewers of the second district, which includes an area within the city of 960 acres and an approximate population of 9,500; 110 acres of this

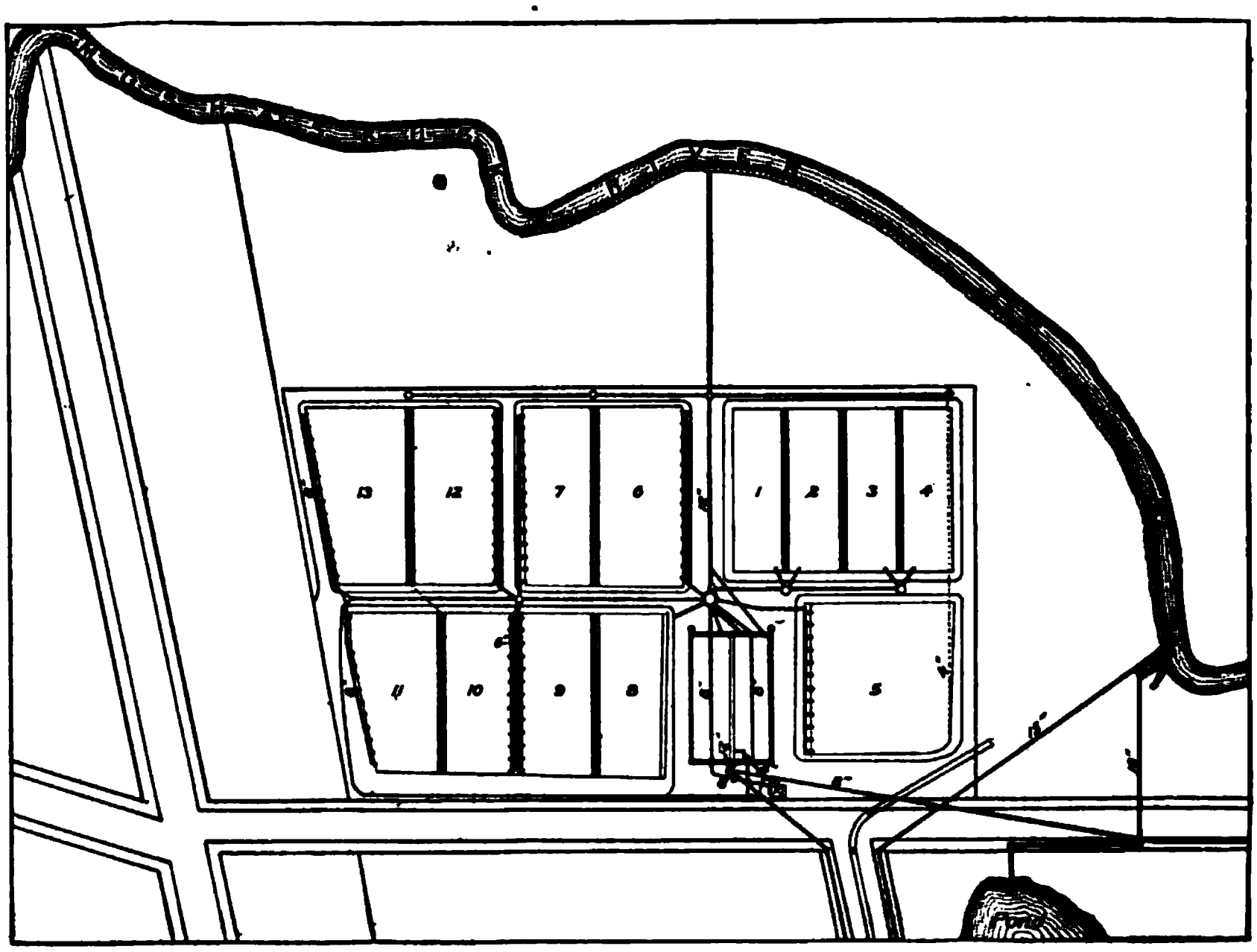

FIG. 4.—Plan of filter areas at Pawtucket, Rhode Island.

area is the most thickly settled portion of the city, having a stated population of 34 persons to the acre. Filter areas are located in the southern part of the city and border upon the Moshassuck River, as shown in Pl. IV. This stream is comparatively small, having an ordinary flow of from 30 to 45 cubic feet per second. It is very much polluted, both above and below the filter areas, by wastes from manufactories, and in view of future complications it was deemed best that the city should not be a party to this pollution. The filter areas, as already constructed, include a little less than 4 acres, about 2.4 acres being the actual area capable of receiving sewage. This is divided, as shown in fig. 4, into 13 beds, 4 of which are designed for sludge beds,

[1] Refer to Eng. and Bldg. Recd., Vol. XXXV, April 24, 1897.

FILTER AREAS AT PAWTUCKET, RHODE ISLAND, AS RIDGED FOR WINTER SERVICE

and are laid out slightly lower than the other beds in order to receive the sludge from the bottom of the tanks.

Covered sewage tanks have been provided, into which the sewage is first received, and from which it is discharged upon the beds as desired. The sewage flows to these tanks from the city by gravity. Arrangements have also been made by which the flow of sewage can be shut off from the tanks automatically and turned into the storm overflow whenever the amount delivered is so increased by a storm as to tax the capacity of the tanks above the average or above any amount to which the apparatus has been adjusted. After the cessation of the storm and the consequent return of the sewage to the average rates, the gates to the settling tank open automatically, allowing the sewage to again flow into them. In ordinary use sewage is received into the tanks for about twenty-four hours and then turned upon the beds under irrigation at the rate of 100,000 gallons per acre.

Work was begun on the disposal areas in 1893. Generally speaking, the work at Pawtucket has been well carried out and the operation of the plant is successful.[1]

Cranston, State institutions.—The State institutions at Cranston, Rhode Island, include a house of correction, State almshouse, State hospital for the insane, State prison, the Sockanosset School for Boys, and the Oak Lawn School for Girls. They are situated in the midst of a tract of about 500 acres of land owned by the State. Sewage disposal by land treatment was first proposed at Cranston in 1884, and carried out in 1895, since which time it has been successfully operated.

The filtration is said to work well in winter, the sewage reaching the field ordinarily at temperatures of about 40°, 42°, or 43° F.[2]

Providence.—Sewage disposal on a large scale has also been projected for the city of Providence, which had a population in 1890 of 132,146. As the matter now stands, it is proposed to partially purify the sewage by chemical precipitation and discharge it into tide water at Fields Point. Main intercepting sewers have been under construction for the last few years with this end in view.[3]

Woonsocket.—Sewage-disposal works have also been projected for Woonsocket.

CONNECTICUT.

Bristol.—A recent example of a combination broad-irrigation and intermittent-filtration plant is at Bristol, Conn. The population of this town in 1890 was 7,382. In 1892 a number of suits were brought to restrain the discharge of crude sewage into a stream flowing through

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[1] Refer to Eng. News, Vol. XXXV, January 2, 1896, where a very complete account by George A. Carpenter, city engineer of Pawtucket, designing and constructing engineer of these works, may be found.

[2] Refer to Seventeenth Ann. Rept. Bd. Charities and Corrections of R. I., 1895; also Eng. and Bldg. Record, Vol. XIII, March 4, 1896.

[3] The Providence sewage-disposal data are very extensive; for a digest of the same refer to Sewage Disposal in the United States.

the town. The suits have been held in abeyance pending the construction of sewage-purification works.

Plans for a sewerage and sewage-disposal system were prepared in 1892, but the actual work of construction was delayed about three years awaiting necessary legislation. Acting under the advice of Mr. McKenzie, the town's engineer, 80 acres of land were purchased at $35 per acre for the purpose of constructing filter beds and also for utilizing sewage by broad irrigation. The necessary sewers and a portion of the disposal area were constructed in the year 1895.

The filter areas as thus for prepared include about 6 acres. The material is coarse sand and gravel. Sewage is distributed to them by means of 15-inch and 12-inch carriers. The underdrains, so far as laid, are 8 inches and 6 inches in diameter and 25 feet apart. It is not intended to underdrain the irrigation area. The cost of preparing 6 acres of filter beds, with the necessary appurtenances, was about $9,000. No definite statements can yet be made as to the results of purification or irrigation at this place.

Danbury.—Population in 1890, 16,552. A few years ago the Wolf disinfecting process, which consists in dosing the sewage with sodium hypochlorite formed by a partial electrical decomposition of a solution of salt and water, was applied. The process, as applied at Danbury, proved inefficient, and suits were brought enjoining the city from discharging its sewage into Still River. The court recommended intermittent filtration, adjudged costs against the city, and required discontinuance of the discharge after May 1, 1897. Under these circumstances the town purchased an extensive tract of land, a portion of which is stated to have been prepared for use in intermittent filtration.[1]

Lake Wauremaug.—This lake, which is surrounded by a number of hotels and cottages, has abrupt, rough, and rugged shores, which render an economical, safe disposal of sewage somewhat difficult. Areas for land treatment are entirely lacking. Under these circumstances a committee of the State board of health in 1894 recommended the treatment of all human fæces and urine by a dry-earth system, and the treatment of laundry and sink wastes by filtration in trenches on sloping ground, somewhat after the method successfully used at Wayne, Pennsylvania. It is understood that these recommendations have since been carried out.

Litchfield.—Population in 1890, 3,304. The first sewage-irrigation field in Connecticut was inaugurated at this place in 1890. Area of same, 4 acres. No details as to method of operation or success attained are at hand.[2]

Manchester.—Population in 1890, 8,222. It is stated that a sewage-disposal plant by land purification has recently been constructed. No information as to details is at hand.

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[1] Refer to Eng. News, Vol. XXXIV, August 29, 1895.

[2] Refer to Fourteenth Ann. Rept. Conn. St. Bd. Health, 1891.

Meriden.—The sewage-disposal works at Meriden furnish an example of combined irrigation and intermittent filtration. The population of Meriden was 21,652 in 1890. Waterworks were built in 1869.

The gradual extension of sewers having led to a considerable pollution of Harbor Brook, a small stream flowing through the central and lower part of the town, the question of sewage purification gradually became a leading one until a special committee was appointed, in 1891, to investigate and report on the general question. This committee submitted reports of engineers recommending broad irrigation, supplemented by intermittent filtration, on a tract of land of about 150 acres, which was subsequently purchased for this purpose. According to statements in Engineering News, the disposal area as originally planned included some 32 acres for broad irrigation and 14 filter beds, 8 of which are 150 feet by 350 feet and the balance one-half that size. That portion of the disposal area which has been laid out in beds is stated to consist of fine soil 3 feet deep, below which is a layer of sand and gravel of unknown depth, admirably suited for filtration. The fine, deep soil contains a layer of rather poor, brownish-black material about 8 inches thick, below which is red loam sand, finely divided and nearly without grit. The sand and gravel farther down are very coarse, most of the sand being coarser than ordinary building sand.

In constructing the filter areas only about 12 inches of the top soil was removed, leaving about 2 feet of the fine material above the coarser subsoil. The filter beds have been underdrained with 6-inch tile placed 2½ feet below the surface at their upper end and 5 feet below at their lower ends. Inspecting chambers are placed at the junction of each under drain with the main drain. The main drain discharges into water carriers leading to a neighboring river.

Sewage was first discharged upon the original filter areas in September, 1893. It was then reported that very little effluent appeared in the underdrains, and that the discharge from them grew less and less until finally practically none appeared. The clear inference is that the effluent passed on down below the drain pipes and sank into the coarse material below.

Considerable trouble has ensued at Meriden, chiefly by reason, apparently, of neglect of the fundamental principles of sewage purification and utilization, not only as worked out in detail by the experiments of the Massachusetts State board of health, but as practiced successfully for many years abroad. The beds have not only been overdosed, but in their original preparation the exceedingly fine material above the subsoil was partially left instead of being fully removed, with the result that the filtration was not only very slow, but the filtering material was soon clogged. In 1895 all the beds were stripped of top soil and fine sand. Since that time the results have been much better.

So far as can be learned, no special attempt has yet been made to

If the results given in the foregoing are maintained permanently the Chautauqua Assembly sewage-disposal plant may be regarded as of a very high order.

In 1893, from July 1 to October 1 (ninety-two days), the cost of labor was: Superintendent and engineer, $255; helper, $131; total, $386, or at the rate of about $4.20 a day. The amount of chemicals used per diem is stated to average about as follows: Lime, 1 barrel; alumina sulphate, 30 to 40 pounds; copperas, 2 to 5 pounds. Fuel is estimated to cost about 30 cents a day. Taking labor at $4.20, fuel at 30 cents, and chemicals at $1.75, we reach a total of $6.25 a day. Assuming an average attendance of 4,000 people during the season, the daily cost per capita is found to be 0.156 cent, or at the rate of 57 cents per capita per year. Chemicals on the foregoing basis cost about 16.1 cents per capita per annum. Taking the actual flow of sewage as averaging about 125,000 gallons a day, we reach a cost per million gallons treated of $8.88 for lime, $7.76 for alum, and $1.28 for copperas, or a total of $17.92 per million gallons treated, which again indicates somewhat greater expense for chemical treatment than would be required for treating the same amount of sewage on land. Inasmuch, however, as the results were largely experimental in 1893, it is possible that later figures would show a marked reduction in cost. Chemical treatment will, however, even under the most favorable circumstances, cost more than land treatment, other conditions being, of course, assumed as equal.[1]

Far Rockaway.—Population in 1890, 2,288. Plans for sewerage and sewage disposal were approved by the New York State board of health in 1895; they include the collection of the sewage of the village at central points, from which it is to be pumped, by means of an electric motor and motor pumps, to a disposal field, where it will be purified by land treatment. It is understood that the work is at present under construction.

New Rochelle.—Population in 1890, 8,217; at present it is perhaps 11,000. A chemical purification plant, designed to treat eventually 750,000 gallons of sewage a day, was carried out in 1894 at an estimated cost of about $19,000. In addition to this sum, 2 acres of land purchased, right of way, legal expenses, etc., were estimated to cost about $4,380, or a total of about $23,380. Statements are lacking as to either the efficiency of the process or just the method of treatment pursued.[2]

Hemlock Lake.—The domestic water supply of the city of Rochester is obtained from Hemlock Lake, about 30 miles southerly from and at an elevation of 386 feet above the city. The works for bringing this supply to Rochester were constructed in 1874 and 1875, about which time the attention of the citizens of Rochester as well as those of the

[1] Refer to Eng. News, Vol. XXXI, February 1, 1894.

[2] Refer to Eng. News, Vol. XXXIII, February 28, 1895; and Eng. and Bldg. Record, Vol. XXXI, March 9, 1895.

surrounding cities and towns was attracted to the lake as a desirable point for summer residence. In 1892 there were in use about 120 cottages and several hotels and summer boarding houses, and the summer population about the margin of the lake, including transient visitors, was from 800 to 1,000 persons.

In order to care for the sewage and house wastes the city of Rochester constructed in 1886 a pail system by which the night-soil and garbage from the cottages and hotels are collected and removed to the foot of the lake, where the material is deposited in narrow trenches in thin layers, and, after treating with lime, each layer is covered with about 6 inches of dry earth. This process is repeated daily until the trench is nearly filled, when the remainder is rounded up with earth and a new trench is started. The surface of the full trench is then cultivated and cropped, and after a suitable period the same land is again used. The trenches were originally made about 3 feet deep, but experience indicates much more rapid destruction of the organic matter near the surface than at the lower levels. It has been found that after a period of three years the same trench can be used again. The plant includes a building with convenient arrangements for washing the pails during the summer and for storing them in winter, as well as a flat-bottomed scow for transporting the sewage receptacles on the lake, and a tramway and pier, with a total length of 2,200 feet, by which they are transported from the lake to the place of treatment. The approximate cost of the plant to April 6, 1891, including surveys, building, scow, wagon road, tramway, carts, pails, and land, was about $10,000. The yearly cost of operation is from $1,500 to $1,700. In winter only a few of the dwellings are in use and the collections are made weekly by wagon.[1]

Bath, Soldiers' and Sailors' Home.—Mr. Power's patented process, described on page 62, is in use at this place, where the permanent population may be taken at from 1,200 to 1,500. Chemicals are stated to cost fully $2,000 a year. Including fuel, labor, and other expenses, the sewage purification costs about $3 per capita per annum. A good opportunity exists at this State institution to elevate the sewage by pumping onto porous lands owned by the State just back of the home, where it could be efficiently utilized in irrigation.

Batavia, State Institution for the Blind.—The average quantity of sewage of this institution is estimated at about 10,000 gallons a day, this quantity being based upon an average daily consumption of water of 50 gallons per capita for the 200 officers and inmates. Chemical-treatment works costing about $6,500 and an outlet sewer costing $6,000, or a total of $12,500, were constructed in 1890–91. No statements as to the efficiency of the process are at hand.

Vassar College.—Vassar College is situated near the town of Pough-

[1] Refer to Ann. Repts. Ex. Bd. City of Rochester, and Sewage Disposal in the United States. The city of Rochester is now (1899) purchasing a strip of land about Hemlock Lake, including all the cottages, and this collection system will accordingly soon be discontinued.

keepsie, a short distance back of the city, upon a small stream, which reaches the Hudson River by a roundabout course of something like 6 miles. For a number of years previous to 1895 the college sewage flowed to a series of covered tanks, where it underwent a rapid filtration through peat, gravel, and other substances. The effluent from this process, while considerably clarified, was still objected to as unfit to pass into a small outlet creek, the township health officer alleging that its discharge was injurious to riparian owners below.

After considerable discussion, in which various projects were suggested, a plan for disposal by intermittent filtration and broad irrigation was prepared and carried out by Messrs. Noyes and Hazen in the fall of 1895. Under this plan the sewage first passed into a screening chamber provided with a screen rack formed of iron bars ¼ by 2 inches in diameter, placed seven-eighths of an inch apart. The sewage enters the screening chamber parallel to the screen rack and not against it. The matter collected at the screen is taken out each day, and after draining on a platform is removed to the boiler house and burned. From the screening chamber the sewage flows to a reservoir of 44,000 gallons capacity, from which it was pumped to the disposal area, which consists of two filter beds with a total area of 1.03 acres exclusive of the embankment. The filtering material is a rather coarse sand with an effective size of grain of from 0.30 to 0.40 millimeter.

The level of the ground water was found to be about 15 feet below the prepared surface of the filter areas, and as there was a gully near by which afforded a free outlet for the ground water, underdraining was deemed unnecessary.

The filter beds provided are regarded as sufficient to receive the entire sewage of the college, but as there was a considerable area of sandy soil near by at a somewhat greater elevation, the force main was extended to a point commanding this area, so that during the growing season several acres of land can be utilized for broad irrigation. In this way the fundamental principle of effective sewage utilization has been recognized in these works, the sewage going to the land when necessary for the best results of agriculture and to the filter areas when not needed on crops, thus insuring an efficient filtration at all times without reference to cropping.

Complete records as to the quantity of sewage do not appear to have been kept, although during the months of February and March, 1896, the average daily quantity is stated as 56,000 gallons, the range being from 32,000 to 113,000 gallons. The sewers receive roof water and the higher quantities are stated as due to accessions from this source.

The total cost of the works as constructed, including the preliminary expense involved in considering the various projects proposed before the final adoption of the sewage-utilization project, is stated at $7,500, exclusive of the land.

Chemical examinations have been made of the water taken from the brook receiving the effluent, above the point where the effluent enters as well as below, with the result of showing that the stream below the effluent now carries no trace of sewage contamination. A great improvement in the condition of the stream is also shown by analyses made before and since the beginning of the filtration by Mrs. Ellen H. Richards, one of the trustees at Vassar College, and analyst of the Massachusetts State board of health. The examinations are to be continued for considerable length of time in order to gain information as to the final effect on the effluent and as to other questions of interest to those planning similar works. The enterprise of Vassar College in carrying out so thorough a system and also in causing systematic examinations to be made for the purpose of acquiring information for future guidance is highly commendable.[1]

PLANTS PROJECTED IN NEW YORK.

Albion.—Population in 1890, 4,586. Plans for sewage disposal by intermittent filtration were approved by the State board of health in 1890. The sewage will be delivered at the filtration fields by gravity, and the topographical conditions are such as to admit of utilization in agriculture by broad irrigation on porous, sandy lands.

Cobleskill.—Population in 1890, 1,822. Plans for sewage disposal by chemical purification were approved by the State board of health in 1893. No information is at hand as to whether or not land-purification processes have been considered.

Cortland.—Population in 1890, 8,590. Plans for purification of the sewage of the town by chemical treatment were approved by the State board of health in October, 1893. The plans also include possible filtration through land, should a high degree of purity be found necessary. It is proposed to use lime and sulphate of alumina as precipitants. The plans, as approved, include a tank area for from 9,000 to 10,000 people, with arrangements whereby the capacity can be increased as required. The report of the engineer does not state whether or not the locality would admit of land-purification processes.

Flatbush.—Under the health laws of the State of New York, the governor may, on presentation of evidence as to the existence of a nuisance, order the same to be abated under plans subject to the approval of the State board of health. In 1894 Governor Flower issued such an order with reference to the sewage of the village of Flatbush, on Long Island, which then grossly polluted Mill Creek. No information is at hand as to the action finally taken under this order.

Fort Plain.—Population in 1890, 2,864. This town is situated in the narrow portion of the Mohawk Valley at a place where little opportunity for land purification exists, except that the town incurs the expense of pumping. The cities of Rome, Little Falls, and Utica, on the Mohawk River above Fort Plain, discharge sewage into the river without treat-

[1] For an account of the Vassar College works, see the Engineering Record of June 27, 1896.

ment. Under these circumstances a chemical purification plant was approved by the State board of health in 1893.

Fonda.—This place, with a population in 1890 of 1,190, is also situated in the narrow valley of the Mohawk River below Fort Plain. For reasons similar to those stated in the case of Fort Plain a chemical-purification plant for this place has been approved by the State board of health.

Fulton.—Population in 1890, 4,214. This village is situated on the Oswego River, 12 miles from Lake Ontario. Chemical-purification works using lime and sulphate of alumina for precipitants, and estimated to cost $19,500, were approved by the State board of health in 1894. The water supply of the city of Oswego is taken from the Oswego River about 10 miles below. The engineer's report does not state whether land-purification processes are feasible or not.

Gowanda.—The present population of this place is stated at about 2,500. Sewage-disposal works by the process of sedimentation followed by upward filtration were presented to the State board of health in 1895. The details are too meager to give any certain indications as to the probable success of the process as specially applied at this place. The cost of the tanks is estimated at approximately $4,000, with a fixed charge of $800 per annum for maintenance.

Herkimer.—The township of Herkimer, which includes the village, had a population in 1890 of 4,666. The present population of the village is, however, stated at about 4,700. Plans for sewage-disposal works were approved by the State board of health in 1893. They include chemical precipitation applied substantially as at Fort Plain and other towns of the Mohawk Valley.

Holly.—Population in 1890, 1,381. Plans for sewage purification by intermittent filtration were approved by the State board of health in 1890. The topographical conditions are such as to permit the use of the sewage in broad irrigation.

Jamestown.—Population in 1890, 16,038. Sewage-disposal works have been projected, but whether land processes will be used is unknown.

Ilion.—Population in 1890, 4,057. Plans for chemical treatment by the use of lime and sulphate of alumina were approved by the State board of health in 1895. As at Fort Plain, Fonda, Herkimer, and other places in the lower Mohawk Valley, no information is given in the report as to the possibility of applying land purification. This universal omission must be considered extraordinary in view of the water supplies on the Hudson River at and about the mouth of the Mohawk and just below.

Lyons.—Population in 1890, 4,475. Plans for sewage disposal and sewerage were submitted to the State board of health for approval in the summer of 1897. They include purification of the sewage by irrigation and filtration.

Mount Vernon.—Population in 1890, 10,830. Plans for treating the sewage by J. J. Power's patented process were approved by the State board of health in 1893.

North Tarrytown.—Population in 1890, 3,179. Sewerage and sewage-disposal works for this place were approved by the State board of health in 1894. The purification is to be by chemical treatment. The details given in the published reports are exceedingly meager.

Oneida.—Population in 1890, 6,083. This village is situated in the Mohawk Valley above Utica. Plans for the purification of sewage by chemical treatment were approved by the State board of health in 1893.

Pelham Manor.—Plans for chemical treatment of the sewage of this place were adopted by the State board of health in 1894. From the meager details given in the reports it is inferred that Mr. Power's patented process is to be used.

Rochester.—Population in 1890, 133,896. General plans for treating the greater part of the sewage of that portion of Rochester lying east of the Genesee River, including at present a population of about 75,000 persons, were prepared in 1888, but have remained thus far in abeyance. The plans as prepared propose a partial chemical purification by lime treatment, with discharge of the effluent into the Genesee River. There is a fine opportunity to utilize the sewage of the east side at Rochester by broad irrigation on sandy soils in the neighboring town of Irondequoit, which are now largely devoted to growing vegetables for the Rochester market. In view of the successful experience on a similar soil at Gennevilliers, in France, as described in Water-Supply and Irrigation Paper No. 3, the author can not but think that if the city of Rochester were to finally construct a chemical-purification plant as proposed it would miss the great opportunity of its municipal life.

Williams Bridge.—Population in 1890, 1,685; estimated at present at about 5,000. Plans for chemical treatment of the sewage were approved by the State board of health in 1894. The details of the plans as given in the reports are very meager.

NEW JERSEY.

Atlantic City.—This place is a well-known seaside resort, which has many visitors in winter, but a much larger number in summer. Its population in June, 1890, was 13,055, against 5,477 in 1880. It is said that during the height of the summer season 150,000 people sometimes visit this place.

Atlantic City is one of the few places in the United States where the sewerage and sewage-disposal systems are owned and operated by a private company. The purification plant in use consists, in effect, of an elevated bed in which sand with hay below is used as a separating material and from which the effluent falls in small streams about 3 feet to gathering gutters leading to the effluent pipe. The results gained are extremely unsatisfactory. Indeed, with the large quantity treated

at the present time it is doubtful if any improvement is effected. The answer to a recent letter of inquiry refers to the Atlantic City sewage-purification works as a great farce.

East Orange.—The population of this place in 1890 was 13,282. Sewage-disposal works with chemical treatment supplemented by filtration through land were constructed in 1887 and 1888. The chemicals used are lime and sulphate of alumina. So far as known, no attempt to raise crops on the filter areas has ever been made. The works are now out of use, the sewage going to the Passaic River by way of the Newark sewers.

Essex Fells.—This place is an improved suburban-residence district, with a daily flow of sewage of about 20,000 gallons. Originally the purification was merely such as could be obtained by sedimentation in a tank, supplemented by the flow of the effluent through a mass of broken stone, and thence into gravel. Two filter areas capable of purifying double the present flow were constructed early in 1897.[1]

Freehold.—Population in 1890, 2,932. A disposal plant by broad irrigation was brought into use in 1893. For this purpose 16 acres of land were purchased, upon which the sewage is delivered by gravity. A portion of this has an unfavorable peaty soil with a surface of from 6 to 12 inches of bog iron ore. The remainder is greensand, marl, and clayey gravel. The cost of the land, including right of way, was $4,120, and with fencing and preparation, $6,207. Engineering and superintendence cost $1,944. The entire force of labor consists of one man at $300 per annum. The disposal area was seeded with Hungarian grass the first year, which sold standing for $45, but the hay is said to have molded after being housed. An attempt to cure this grass the second year is also said to have failed. Probably if Hungarian grass is the proper crop to raise on this area, ensilage would be the best way to preserve it.[2]

Lawrenceville School.—A system of subsurface irrigation was carried out at this school in 1883. Additions thereto, either by intermittent filtration or by broad irrigation, were proposed in 1893. As to whether the improvements have all been carried out there is no information at hand.[3]

Long Branch.—The winter population of this place does not exceed 7,000 or 8,000, although the population in summer is estimated at from 80,000 to 100,000. Like Atlantic City, this place has granted a franchise for sewerage works to a private company. Chemical-precipitation and mechanical-separation sewage-disposal works were constructed in 1886. Definite information as to results is lacking.[4]

Morris Plains Asylum.—Works for sewage disposal by sedimenta-

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[1] Refer to Eng. and Bldg. Record, Vol. XXXVI, July 3, 1897.

[2] Refer to Seventeenth Ann. Rept. New Jersey St. Bd. of Health, 1893.

[3] Refer to Trans. Am. Soc. Civ. Eng., Vol. XVI, 1887; Eng. and Bldg. Record, Vol. XVI, 1886; and Sewage Disposal in the United States.

[4] Refer to Eleventh Ann. Rept. New Jersey St. Bd. of Health, 1887.

A

B

SEWAGE DISPOSAL AT PLAINFIELD, NEW JERSEY

A, Main carrier as seen from screen tank (before erection of building). B, Distributing channel in bed No. 1

tion and subsurface irrigation were constructed at this State institution in 1887. The sewage is also dosed with a small quantity of sulphate of alumina. No information is at hand as to whether sewage irrigation could be profitably used.[1]

Plainfield.—The present population of Plainfield is about 13,000. It is chiefly a residence town, a very large portion of the residents being New York City business men. The construction of a water supply a few years ago has had the usual result of emphasizing the need of sewers, but no practical move was made in this direction until 1892. It was then resolved to construct a sewerage system with purification by intermittent filtration and broad irrigation. The construction of the works was begun in 1894 and completed in 1895. The land selected for sewage disposal lies at an elevation of from 50 to 70 feet above mean sea level and can be mostly reached with the sewage of the town without pumping. For one district, however, it is arranged in the future to drain to a pump well, from which the sewage will be raised by automatic electric pumps into a neighboring main, whence it can flow by gravity to the disposal works. The works at Plainfield are of further interest because of a trial there of cultivation of the filtration area. The result of such experiment with indian corn is well shown on Pl. I of Water-Supply and Irrigation Paper No. 3, and on Pl. V of this paper. The flow of sewage is stated at present to amount to from 11,000 to 13,000 gallons per hour at 11 a. m., gradually diminishing from that time to 5,000 gallons at about 4 p. m., and again increasing from 7 p. m. to 11,000 gallons per hour at 11 a. m., as stated. The total flow in twenty-four hours is stated as about 230,000 gallons. The works were constructed under the direction of A. J. Gavett.

Princeton College.—Sewage disposal by broad irrigation was carried out at Princeton several years ago. An average daily flow of sewage of from 7,000 to 10,000 gallons is purified on a sloping field of about 4 acres which has 6 inches of black soil resting upon a homogeneous clay subsoil. The entire area is drained to a depth of 4.5 feet with 2-inch tiles laid 30 feet apart. Sewage is applied from a line of troughs at the upper margin of the field, which are changed from place to place as necessary.[2]

Summit.—Population of the township in 1890, 3,502. Sewage purification by intermittent filtration was first operated in 1892. The disposal area consists of 26 acres of land, of which 10 acres have been laid out. The following bacteriological examination, made by Dr. Richard N. Connolly, bacteriologist to the Passaic River Commission, indicates defects of some sort in these works.

Sample of raw sewage taken December 31, 1896, showed bacilli coli communis very numerous, with a total number of bacteria per cubic centimeter of 1,112,250.

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[1] Refer to Eleventh Ann. Rept. New Jersey St. Bd. of Health, 1887.

[2] Refer to Twentieth Ann. Rept. New Jersey St. Bd. Health, 1896.

A sample of the filtrate from the westerly outlet taken at the same time also showed bacilli coli communis very numerous, with a total number of bacteria per cubic centimeter of 1,098,900.

A sample of the filtrate from the northerly outlet, also taken at the same time, showed bacilli coli communis numerous, with a total number of bacteria per cubic centimeter of 645,440.[1]

Westfield.—This town had a population in 1897 of about 3,000. Sewerage and sewage disposal works were carried out in 1895 and 1896. The method of disposal is by means of intermittent filtration and broad irrigation. For the former four level beds of about three-quarters of an acre each have been prepared on the highest part of the disposal field, which lies at an elevation of about 80 feet above tide water. The soil ranges from a fine sand to a coarse gravel. For the present 12 acres have been purchased, the portion not included in the filter beds to be used for broad irrigation. Thus far only one man is found necessary to take care of the sewage. The cost of the plant, including land, was $8,435.[2] F. A. Dunham was designing and constructing engineer.

PENNSYLVANIA.

Altoona.—Population in 1890, 30,337; in 1895 the population was estimated at 35,500. The town is located at the base of the Allegheny Mountains, between the elevations, 1,110 and 1,350 feet above tide, and near the head waters of the Juniata River. A sewage-disposal plant, constructed in 1896 and 1897, is designed to purify the sewage of a little less than one-half of the city, which originally drained southward toward Hollidaysburg, the county seat of Blair County, which is situated on the stream originally receiving the sewage a few miles down.

The pollution of the streams receiving the Altoona sewage has been a source of controversy for many years, and in 1882 suits were brought against the city for polluting springs on property about 11,400 feet southward from the city limit. This case was finally decided against the city, and claims of damages, interest, and costs to the amount of $6,555.36 were compromised in 1895 for $2,812.45.

Early in 1895 surveys for a sewage-disposal plant were made by Mr. Harvey Linton, city engineer. Messrs. Rudolph Hering and Allen Hazen were employed as consulting engineers. The details of the Altoona sewage-disposal operations are exceedingly interesting, but too extensive to be gone into here, and we may simply state that the filter beds have a capacity of about 750,000 gallons a day. The land purchased for sewage disposal amounts to nearly 96 acres and cost $12,000. Of this nearly 70 acres are available for sewage purification. The new works were first operated in June, 1897. It is intended to raise corn upon the filter areas.

The specifications for this work, as prepared mostly by Mr. Hazen,

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[1] Refer to Eng. News, Vol. XXVIII, December 8, 1892, and Sewage Disposal in the United States.

[2] Refer to Twentieth Ann. Rept. New Jersey St. Bd. Health, 1896.

present some interesting features. The following is the clause covering grading and embankments:

The general object of this work is to divide up the land into a series of level plats surrounded by embankments, so that each can be separately flooded without disturbing the others, and to prevent the overflow of the land by the stream in time of flood.

. . . . . .

The land should be kept in as loose and porous condition as possible, and to that end all that part of the area to be filled shall be plowed 1 foot deep and left in loose condition before commencing to fill, and the elevations of the filling shall be carried to such additional elevation as may be directed by the engineer, to allow for subsequent settlement to bring all parts of the bed to the same ultimate elevation.

The dividing embankments shall be solidly constructed and rolled if necessary. The stone removed from the land may be largely placed in them if not otherwise required. The outside embankment as low as ordinary high water shall be paved with stones removed from the field in such exposed places as may be directed by the engineer, and the remainder of the slope and top carefully sodded with firm, healthy sods.

Land stones over 4 inches long are to be removed from the surface material as fast as the same is removed and are to be placed in the embankments or along the river to prevent washing, as will best serve the interests of the work, and as may be directed by the engineer.

After removing the stones the surface of the beds shall be carefully graded and smoothed and left in porous condition, free from compacting from wheels or hoofs, and ready for receiving sewage.[1]

Norristown, State Hospital for the Insane.—The total population of this institution is about 1,500, and the total daily consumption of water about 325,000 gallons, or 150 gallons per capita. A sewage-disposal plant, with purification by filtration and broad irrigation, was constructed in 1885. These works are said to have been specially successful.[2]

Reading.—Population in 1890, 58,661. The proprietary process of the Pennsylvania Sanitary Sewage Company was carried out in 1895. It is claimed that the works have sufficient capacity to purify 15,000,000 gallons of sewage a day. The following statement embodies the main points of these works:

The sewage falls by gravity into reservoirs 20 feet in diameter, with coke filters 12 inches deep, through which the sewage first passes in order to screen out the coarser suspended matter. The reservoirs are ventilated by special passages which surround the smoke flue and are expected to discharge foul odors at a height of about 100 feet.

The sewage is drawn from the reservoir into a suction chamber, from which it is pumped to filter beds on the river banks, about a mile from the pumping station. These beds are two-story structures of brick, stone, and iron, 250 by 50 feet, each story being subdivided into ten compartments, making a total of twenty compartments 25 by 50 feet. The filter beds are divided into upper and lower sections, in order to combine aeration with filtration. The filtering material of the upper section consists of fine sand 2 feet thick. After percolating through

[1] Proc. Eng. Club of Philadelphia, Vol. XIV, July–September, 1897.

[2] Refer to Colonel Waring's Sewerage and Land Drainage, 1889.

this the sewage falls 8 feet to-a lower filter, which is formed of various grades and sizes of filtering material. Inlets are provided in which air is to be circulated in the coarser material of the lower section. The effluent water is discharged directly into the river.

The author can not but think that the proposition to purify 15,000,000 gallons of sewage a day by this plant must be intended as a joke.[1]

Wayne.—This place is a suburban village with a population in 1890 of 997. It has grown rapidly, and at present the population is much greater. There are no manufactories. Sewage disposal by surface irrigation was carried out in 1891. The disposal area includes 11 acres of sidehill land, with creek flowing through the middle. A portion of the land is timbered, as shown by fig. 2 in Water-Supply and Irrigation Paper No. 3 and by Pl. VII in this paper.

The sewage flows by gravity to the pumping station, whence it is forced to distribution wells on adjacent highlands, from which it flows down the sidehill through heaps of broken stone. At various places below cinder banks are formed. A very efficient filtration is said to be obtained by this process in course of a few hundred feet below. In 1892 the average daily quantity of sewage was established at about 200,000 gallons. During that year five crops of grass were raised on the irrigated land.[2] The effluent water is discharged into the river.

WEST VIRGINIA.

Weston, State Insane Hospital.—Plans for sewage disposal by chemical precipitation, supplemented by broad irrigation, on about 27 acres of land on which it was intended to grow crops were prepared in 1891. In view of the sewage farming offering an opportunity for employing a considerable number of harmless insane in light outdoor labor, it was believed that this project was an especially feasible one. Thus far, however, the West Virginia legislature has not appropriated the $40,000 necessary in order to carry out the project in full detail.[3]

TEXAS.

Paris.—Population in 1890, 8,254. This town is finely located in northwestern Texas, about 14 miles from Red River, at an elevation of 588 feet above tide water.

Sewers were constructed in 1894, discharging into a small stream known as Bankers Creek. Soon after constructing a main sewer, farmers on this creek below the outfall brought suits for damages aggregating $15,000. Trial of one of them resulted in a verdict against the city of $900.

The suits had the effect of forcing attention to some other means of sewage disposal, and in the early part of 1897 a system of disposal

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[1] Eng. and Bldg. Record, Vol. XXXI, May 4, 1895.

[2] Refer to the Am. Arch., July 2, 1892; Eng. News, Vol. XXVIII, November 3, 1892; and Sewage Disposal in the United States.

[3] Refer to Jour. of W. Va. House of Delegates, February 18, 1891.

by intermittent filtration was begun. For this purpose the city purchased 10 acres of land for $750, of which 5½ acres have been laid out. The cost of constructing 5½ acres of filters is given at $3,730. The present daily flow of sewage is from 35,000 to 40,000 gallons. The sewage-disposal areas are cared for by one man, who is paid at the rate of $420 a year. It is proposed to crop with alfalfa in 1898.[1]

San Antonio.—Population in 1890, 36,673. The city purchased 530 acres of land in 1895, with the expectation of establishing a sewage farm. Information is not at hand as to the present state of the enterprise.

Temple.—Population in 1890, 4,047. It is understood that this place has recently granted a franchise to a private company to construct and operate sewerage and sewage-disposal works.

OHIO.

Alliance.—Population in 1890, 6,707. A chemical-purification plant estimated to cost $18,400 has either been recently constructed or is about to be constructed at this place. As to just the present state of the project, no information is at hand.

Canton.—Population in 1890, 26,189; present population estimated at about 35,000. The outfall sewer originally discharged raw sewage into the main branch of the Nimishillen Creek. Complaints were made several years ago by the owners of land abutting on the creek below the outlet of the sewer, thus bringing the question of sewage purification before the city authorities, who acquired 28 acres of land at and about the sewer outfall for the purpose of providing some method of purification. Chemical treatment was finally decided upon as adequate to the requirements, although the relative cost of chemical purification versus land treatment does not appear to have been gone into. The works were constructed under the supervision of L. E. Chapin, city engineer.

The plant was first started in May, 1893, since which time all the sewage of the city has been treated. The following analyses, made by Dr. Curtis C. Howard, in which the results are stated in parts per 100,000, indicate the degree of purification effected. No. 1 is the average of 24 samples of the raw sewage, and No. 2 the average of 24 samples of effluent taken at the same time as No. 1.

Analyses of raw sewage and of effluent, at Canton, Ohio.

[Parts per 100,000.]

	No. 1.	No. 2.
Free ammonia	0.894	0.676
Albuminoid ammonia	.326	.112
Chlorine	2.14	2.05
Total solids	49.3	41

[1] Refer to Eng. News, Vol. XXXVIII, August 12, 1897.

The cost of the sewage-disposal plant at Canton to March 15, 1897, is as follows:

Land	$4,100.00
Construction	27,215.23
Material	14.70
Total	31,329.93

The cost of maintaining the works in 1896 was as follows:

Labor	$1,630.00
Coal	356.76
Lime	739.63
Alum	502.75
Oil and waste	33.01
Filter sacks	46.68
General repairs	61.91
Miscellaneous	44.50
New smokestack	137.00
Total for year	[1] 3,552.23

Fostoria.—The population in 1890 was 7,070. Plans for sewage disposal by land purification were prepared in 1895. As to whether they have yet been carried out no information is at hand. The conditions are such as to require pumping to the disposal field. Cost of disposal works is estimated as follows:

24½ acres of land, at $150	$3,675.00
Preparation for beds, including underdrainage, grading, force main, main carrier, and effluent drain	6,425.00
Reservoir, sludge and pump well, necessary buildings, boiler, and pumps	14,920.00
Total	25,020.00

Running expenses with coal as fuel are estimated at about $1,843 per year, without taking into account the profit to be realized from the sale of produce raised on the filter areas.[2]

Oberlin.—This place, which is the site of Oberlin College, had a population in 1890 of 4,376. A sewerage system, with disposal by broad irrigation, was constructed in 1893. The irrigation field includes 15 acres, purchased at a cost of $1,500. In 1894 the daily flow of sewage varied from 35,000 to 40,000 gallons. In addition to broad irrigation, 9 filter beds have also been prepared, of which 3 are devoted to raising woodland rye grass, 3 to alfalfa, and 3 to corn and garden vegetables.

The soil. which consists of yellow clay underlain at a few feet by stiff blue clay, is not specially favorable for sewage disposal. As to the best methods of treating such a soil, reference may be made to a description of the sewage farm at Wimbledon, England, in Water-Supply and Irrigation Paper No. 3. The Oberlin sewage farm is also especially interesting because of the small amount spent in preparation.

[1] Refer to Canton Municipal Reports and Tenth Ann. Rept. Ohio St. Bd. Health, 1895.
[2] Refer to Tenth Ann. Rept. Ohio St. Bd. Health, 1895.

The following are the figures:

6,000 feet of agricultural tile	$256
Tool house	55
Grading and incidentals	166
Small pump and tank	42
Land	1,500
Total	2,019

Some reports as to a nuisance at the Oberlin sewage farm having gained circulation, a committee of the Ohio State board of health inspected it in July, 1895. In their report the committee say that no just cause exists for complaint in respect to the Oberlin sewage farm.[1]

Sewage disposal plants are also reported as projected at Bowling Green, Cambridge, Chillicothe, Columbus, Glenville, Greenville, and Mansfield, Ohio.

MICHIGAN.

Wayne County Poor Farm.—A chemical precipitation plant, costing about $10,000, was first operated at this institution in 1896. Cost of operation, including chemicals and attendance, is estimated at about 80 cents per capita per annum for a population of 800.[2]

St. Johns.—Population in 1890, 3,127. A land-purification project has been proposed.

ILLINOIS.

Pullman.[3]—This farm was laid out in 1880 and 1881 by the Pullman Palace Car Company as a means of purifying the sewage of the model town of Pullman, which is about 14 miles south of Chicago and at present is included within the limits of that city. The population in 1893 was 11,000. The only body of water in the vicinity which could possibly receive crude or raw sewage is Lake Calumet, a lake about 3 miles long, 1½ miles wide, and from 1 to 8 feet deep. The extreme shallowness of this lake, as well as the absence of current, renders it very undesirable as a place for disposing of crude sewage, and the country about Pullman is so flat that it was necessary to pump the sewage to the area selected for farming purposes. The area originally selected comprises about 1,500 acres, though thus far only a small part of this tract has been used. In 1892, with an average daily flow of sewage of about 1,850,000 gallons in twenty-four hours, the land in actual use did not exceed 140 acres.

This farm is of special interest in the present connection, because its original design recognized the principle of having filter areas on which any surplus sewage not needed for the best results in irrigation could be purified. It should not be overlooked that reports have frequently come from Pullman that the sewage was often allowed to flow into

[1] Refer to Ninth Ann. Rept. Ohio St. Bd. Health, 1894 and 1895.

[2] Refer to Eng. and Bldg. Record, Vol. XXXIV, July 11, 1896.

[3] The use of this farm for sewage disposal has recently been discontinued.

Lake Calumet in nearly its natural condition. On this point it may be remarked that the projectors have probably felt that little harm was done to anybody so long as no nuisance was created in the lake or along its margins. The fact that a portion of the ice supply of Chicago was taken from Lake Calumet during the winter has been considered with indifference. Owing, therefore, to either inefficient or indifferent management, the Pullman farm can not be referred to as a specially successful example of sewage purification, although, from the statements made, the utilization has justified in a commercial way the expectations of its projectors. The farm is stated to have yielded in some years a net profit of from 8 to 10 per cent. The designing engineer, Benezette Williams, of Chicago, is entitled to the credit of having made his design sixteen years ago in line with what is universally considered to be the best practice of the present day.

The soil at Pullman is the ordinary prairie black alluvium, about 1 foot in depth, and mostly underlain by a clay subsoil. It is therefore not the most favorable for utilizing a large volume of sewage on a small area. From what has been learned in regard to this farm, it is the author's opinion that a considerably larger area should be used. With this improvement, as well as some additions to the filter area in order to afford sufficient relief in wet weather, it is believed that sewage farming can be made very successful at Pullman, from the points of view of both purification and utilization.

The underdrains are of common agricultural tile, laid about 40 feet apart to an average depth of about 4½ feet. The most satisfactory crops are cabbage, cauliflower, celery, and other vegetables common to market gardening. For some reason the raising of potatoes has not been successful on this farm. Italian rye grass is also reported as unsuited to the conditions, but whether the difficulty is due to climate or soil, or both, is unknown. Very little live stock is kept, because market gardening for the Chicago market is more profitable. During the growing season about forty laborers are employed at the current rates of common labor in the vicinity of Chicago.

The distribution of sewage at Pullman is effected by the pipe-and-hydrant system. For this purpose vitrified tile pipes, tested by water pressure before laying, have been successfully used.

The foregoing short account of the Pullman sewage farm is given here, not because it is an example of the best work in sewage utilization, but because it was the first large sewage farm in the United States, and because, further, it was designed in accordance with the now universally recognized principle of intermittent filtration relief areas. In view of the large experience gained elsewhere, failure to purify the sewage efficiently at all times must, as has already been pointed out, be attributed to the management rather than to the method. Under this head it may be remarked that thus far the American farms, generally speaking, have not realized their full agricultural capacity

by reason of defects in management. We need to develop here, as there have been developed abroad, a class of sewage-farm managers who, having made a specialty of this method of farming, shall be not only informed as to details but qualified to meet emergencies.

As regards sewage-purification works owned and operated by towns, it may be said that the entire separation of the management of the works from local politics will be the first necessary step toward increased efficiency.

World's Fair.—The sewage of the World's Columbian Exposition, in 1893, was purified by mechanical precipitation before discharged into Lake Michigan. The plant assigned for this purpose embodied the method of vertical tanks, an illustration of which may be found at page 556 of Sewage Disposal in the United States.[1]

This plant was placed in charge of Mr. Allen Hazen, who made extensive studies as to its efficiency. The daily quantity of sewage treated varied from about 6 million to 9 million gallons. The total cost of treatment per million gallons was $38.09. The works cost about $55,000, of which $20,000 was for the building.

The cost of the chief precipitant used varied from $20.40 to $47 per ton. Mr. Hazen's results are given in considerable detail, but can not be further gone into here. On the whole his report is adverse to the efficiency of the process.[2]

WISCONSIN.

Menominee Valley.—The sewage-disposal plants in Menominee Valley have been described on page 24, in connection with the discussion of purification of manufacturing wastes. They include Schmidt's Curled Hair Works, McBride's Sanitarium, the National Soldiers' Home, the public institutions of Milwaukee County, and the Miller Brewing Company.[3]

MINNESOTA.

Rochester Hospital for the Insane.—Sewage disposal by chemical precipitation supplemented by intermittent filtration was first operated at this State institution in 1890. The population of the hospital is stated at about 1,050 persons, with a total sewage flow of 60,000 gallons a day. The sewage first flows to tanks of sufficient capacity to handle 75,000 gallons a day, from which, after treatment with chemicals, the effluent is pumped to a filtration area with about 16 inches of surface loam, below which is sand and gravel. This area is underdrained with 3-inch tile laid in lines about 25 feet apart. In spite of the low winter temperature of Minnesota, it is stated that no trouble has been experienced in securing sufficient winter purification. The sewage probably

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[1] Additional illustrations of this plant are given in Eng. News, Vol. XX, August 3, 1893.

[2] The full results of Mr. Hazen's studies of the World's Columbian Exposition sewage-disposal plant may be found in the Twenty-fifth Ann. Rept. Mass St. Bd. Health, 1893.

[3] Refer to Eng. News, Vol. XXXIII, June 13, 1895, and Sixteenth Rept. Wis. St. Bd. Health, 1895–96.

reaches the precipitation tank in cold weather with a temperature of about 45° F.[1]

NEBRASKA.

Hastings.—Population in 1890, 13,584. Stated present population, 15,000 to 18,000. A sewage farm of about 70 acres was carried out in 1891 or 1892. The soil of this farm is open and porous, and, so far as known, has not been underdrained. No information is at hand as to the success experienced in cropping.[2]

COLORADO.

Colorado Springs.—Population in 1890, 11,140. A sewerage system was carried out in 1888 and a sewage farm in 1889. Soon after opening the sewage works a ranchman living 2 miles below the outfall, which is into a small stream with a normal flow of about 50 cubic feet per second and at times with no flow at all, instituted injunction proceedings, claiming that his well was so polluted as to render the water unfit for drinking, and that the water in his irrigating ditch, of which the head gate is about three-quarters of a mile below the sewer outfall, was so foul that stock would not drink it. The matter was arbitrated and the suit withdrawn, the city paying all costs of proceedings and agreeing to divert the sewage and utilize it for irrigation.

A contract was then made between the city and the owner of a tract of about 35 acres of land upon which the sewage could be conveniently diverted by gravity, the city agreeing to pay $300 annually for five years, and the owner on his part agreeing to use the sewage for irrigation purposes in such manner as he deemed best, provided, however, that the sewage be prevented from flowing directly into the creek, and provided further, that if the method of irrigation was not satisfactory to parties on the stream below, the city should take possession of the land and use such methods as it thought best. At the expiration of the contract the city was to have the option of buying the land at a stipulated price. Whether or not this has been done is not known. The irrigation, however, is said to have been very successful. In 1892 sewage was used on 25 acres—15 acres in meadow and alfalfa and 10 acres in vegetables. The crops produced have been very large, and owing to close proximity to market the farm is said to be a paying investment.

As illustrating the demand for water in this section, it is stated that farmers several miles below the sewer outfall, seeing the sewage farm well supplied with water at times when their farms were suffering from shortage, have threatened to enjoin the city from using the sewage for this purpose, and thus compelling it to turn the sewage into the stream for their benefit.[3]

Leadville.—Population in 1890, 10,634. The sewerage system of this

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[1] Refer to Sixth Biennial Rept. of Trustees, 1890, Eng. and Bldg. Recd., Vol. XXIII, and Sewage Disposal in the United States.

[2] Refer to Eng. News, Vol. XXIX, March 9, 1893, and Sewage Disposal in the United States.

[3] Refer to Eng. News, Vol. XXIX, February 23, 1893, and Sewage Disposal in the United States.

A

B

SEWAGE IRRIGATION AT SALT LAKE CITY UTAH

A Main ditch, outlet gate, and field of corn. *B*, Lateral ditch and method of irrigating corn

place was built in 1886 by the Leadville Sewerage Company. The original sewage-disposal works as constructed by this company included a sand and gravel filter about 6 or 7 feet deep, with a surface area of 24 square feet. Whether this extensive sewage-disposal plant is still in use is not known.

Trinidad.—Population in 1890, 5,523. A sewerage system was first operated in 1892. Sewage is first received in a settling tank 50 feet long, 5 feet wide, and 4 feet deep, from which it flows upon land. To the end of 1892 about $1,200 had been expended in preparing the irrigation area to receive sewage. Blue grass was originally proposed as a crop on the farm, because it was supposed that this grass would stand more frequent irrigation than any other crop. A private party owns the irrigation area, on which the city delivers the sewage and pays $500 a year to the owner.

MONTANA.

Helena.—The population in 1890 was 13,134. A sewerage system was first operated in 1889. At this place the sewage is utilized only in the growing season. During times when the ground is so frozen that there is no absorption, sewage flows in natural channels upon the surface. The lower end of the outfall sewer connects directly with the distributing ditches of the farm, which includes 40 acres of land, purchased for $6,100. It is leased at an annual rental of $200. Crops raised are vegetables and nursery stock.

UTAH.

Salt Lake City.—Population in 1890, 44,843. A sewage farm was carried out at this place under the direction of F. C. Kelsey, city engineer, in 1895 and 1896. The daily flow of sewage is stated at 4,000,000 gallons. In addition storm water to the amount of 15,000,000 gallons per day may be expected at different times. The land acquired by the city amounts to 183 acres, of which 80 acres have been plowed and are under cultivation in 1897. It fronts on the Jordan River and the main ditch is extended to the stream, so that when the outfall sewer is running full the flow can be diverted directly to the river without passing over the land. Settling basins to the extent of 30 acres have been prepared.

Sewage was first delivered on the farm on July 11, 1896. No crops were planted that year except 5 acres of corn for fodder. It is intended to improve the farm by erecting buildings, planting shade trees along the highways, and an orchard of 6 acres, which is too high for irrigation, but thus far the money has not been furnished for these improvements.

The results of this extensive sewage irrigation at Salt Lake City will be looked for with interest, the more especially as, when the sewage farm was first proposed, it was thought that neighboring farmers would be willing to take the sewage for irrigation, because all land at Salt Lake City necessarily requires irrigation. The farmers, however, refused to take it, mainly, it is said, from ignorance, thinking it would damage the

crops, clog the ground, and be otherwise injurious. It was for this reason that the city embarked in sewage farming.[1]

The total cost of the sewage farm to January 1, 1897, was: Land, $14,763.45; plowing, $273.42; preparation of surface, etc., $3,452.64; total, $18,489.51.

The total cost of handling the sewage for the last six months of 1896 was $683.36. Assuming an average of 4,000,000 gallons a day, this would be at the rate of about 93 cents per million gallons handled for the six-months period. Probably when the sewage farm is in full operation the cost will be greater, but it will be met by sale of crops.

ARIZONA.

Phœnix.—Population in 1890, 3,152. The waterworks, sewerage, and sewage disposal at this place are all owned by the Arizona Water Works and Sewage Company. According to the information at hand, 160 acres of land have been provided for a sewage farm, on which sewage is largely used for irrigating garden truck by Chinese gardeners. The results are understood to be satisfactory. A view of an irrigated field will be found in Pl. VII.

CALIFORNIA.

Fresno.—Population in 1890, 10,818. Sewers were constructed in 1889. In 1890 a contract was made with Alexander McBean, of Oakland, to take the sewage and purify it by irrigation, the city paying therefor $5,000 per year. Mr. McBean purchased 80 acres of land at the outfall, and during the first year the sewage ran upon it without special attention or care, except when some neighbor saw fit to take it for irrigation. The second year distribution ditches were constructed and the land leased to Chinese gardeners for vegetable gardens and vineyards. The land is now all under cultivation with the various kinds of vegetables commonly in the market, such as potatoes, yams, parsnips, lettuce, celery, beans, peas, and corn. Statements as to the amount of sewage are lacking.[2]

Los Angeles.—Sewage irrigation at Los Angeles is of considerable interest, because the most extensive sewage farming by private owners in the United States is practiced there. The population, according to the census of 1890, was 50,395. In 1894 a conservative estimate placed it at 70,000.

Los Angeles is built upon both sides of a torrential stream, Los Angeles River, at a point about 20 miles from its mouth, and at a distance of about 12 miles from the Pacific Ocean. Sewage irrigation here was originally carried on by a private company, which took the sewage as delivered from the main outfall sewer and conveyed it by ditches to an area on which it was utilized in agriculture as required on various small tracts, the surplus being allowed to flow away into

[1] Refer to the Salt Lake City Municipal Rept. for 1896, and Eng. News, Vol. XXXVII, March 13, 1897.
[2] Refer to Sewage Disposal in the United States.

A SEWAGE IRRIGATION AT PHŒNIX, ARIZONA.

B SIDEHILL IRRIGATION AT WAYNE, PENNSYLVANIA.

the stream unpurified. In the course of time the area originally irrigated became city property, and a large portion of it having been sold for residence sites, many of the landowners objected to sewage irrigation and obtained injunctions restraining its use in this way. According to the statements made there was at one time considerable nuisance from the sewage irrigation. The ditches were not kept clean, and under the hot sun of southern California they gave forth a strong odor. The objection was also made that sewage irrigation was detrimental to the health of the community, but so far as can be learned no facts have ever been produced to support this objection.

The sewage has been mostly used in growing vegetables for the Los Angeles market, and, according to the statements made, its commercial value for such purpose has been considerable.

As the result of several years' discussion the city of Los Angeles has recently constructed a main outfall sewer leading to the Pacific Ocean, along the line of which numerous valves have been placed, as is done at other places where successful sewage irrigation has been practiced, not only for drawing off the sewage for use in agriculture, but for restricting its use to such times as it may be needed.

The soil for a considerable portion of the distance along the main sewer is light and sandy and especially adapted to successful sewage purification, and it is believed that a considerable use of sewage for this purpose will be developed soon.

In 1895 and 1896 a total area of about 1,550 acres was irrigated along the line of the new outfall sewer, the amount of sewage used upon this acreage varying from 8 to 10 cubic feet per second. An area of 800 acres near the city is mainly devoted to raising vegetables. The balance was planted in corn and other fall crops, among which were about 100 acres in potatoes and cabbage. According to the reports of the city engineer for the years 1895 and 1896, the following revenue was realized from the sale of sewage:

Revenue realized from the sale of sewage at Los Angeles, California, in 1895 and 1896.

1895.		
Receipts from the sale of sewage		$3,278.00
Maintenance:		
Salary of superintendent	$1,000.00	
Assistance and labor	625.47	
Repairs, etc	512.50	
		2,137.97
Net revenue		1,140.03
1896.		
Receipts from sale of sewage		$4,009.50
Maintenance:		
Salary of superintendent	$1,200.00	
Assistance and labor	1,675.40	
Repairs, etc	184.80	
		3,060.20
Net revenue		949.30

In 1883 the city of Los Angeles entered into contract with the South Side Irrigation Company, obligating itself to give to said company all the sewage flowing through the San Pedro street sewer, amounting to about 3.58 cubic feet per second. In October, 1895, a second contract was made with the same company, whereby the city agreed to deliver until the expiration of the former contract an additional quantity of 2.39 cubic feet per second, or a total until 1903 of a little less than 6 cubic feet per second. In consideration of the last amount the company has laid a 24-inch cement pipe, 6,000 feet of which lies within the city limits and which will become the property of the city in 1903. The company also has the right to use an additional quantity of sewage by paying the prevailing price for it, which during the height of the irrigation season, in April and May, has been placed at $8 per twenty-four hours for 2 cubic feet per second. The rate is also made $5 for a day run of twelve hours and $3 for a night run, to suit the convenience of the irrigators.

The sewage now controlled by the South Side Irrigation Company is mainly used for irrigating about 2,200 acres of land devoted to vegetable gardening. The sewage is distributed throughout the land irrigated by ordinary open-earth ditches. This land now pays an annual rental of $12 per acre for river-water irrigation and $18 per acre for sewage irrigation, or $6 per acre in favor of the sewage.

On sandy soil with good subdrainage the South-Side Irrigation Company now irrigate successfully during the whole year. Experience has shown that when not actually needing the sewage for irrigation it is better to flood the land than to permit the sewage to go to waste.[1]

Pasadena.—Population in 1890, 4,882. Sewers were constructed from 1887 to 1891, and a city sewage farm was brought into operation in 1893. Its soil is a light sandy loam, with good natural drainage, and includes at the present time an area of 800 acres. The flow of sewage is estimated at about 3 cubic feet per second. According to statements of Mr. Burr Bassell, of the 300 acres actually owned by the city, 140 are used for raising grain and have never been irrigated. Sewage has been used upon the remaining cultivated area as follows: Walnut orchard (4 years old), 60 acres; alfalfa, 25 acres; corn, 25 acres; vege-

[1] In a paper by Mr. Burr Bassell, deputy city engineer of Los Angeles, on the Operation of the Los Angeles outfall sewer and sewage irrigation, which appeared in the Journal of the Association of Engineering Societies for August, 1897, many additional interesting details may be found. In the discussion of Mr. Burr Bassell's paper, James D. Schuyler, a leading California irrigation engineer, pointed out that, in view of the conspicuous success achieved in sewage farming abroad, the policy of constructing an outfall sewer to the ocean must be regarded as questionable, particularly in southern California, where the soil and climatic conditions are all extremely favorable for successful sewage farming. Mr. Schuyler expressed the hope that in the future growth of Los Angeles, when the capacity of the present outfall has been reached, extension of the system would be made in the line of utilization by irrigation and the establishment of a city sewage farm rather than in the duplication of the present sewer to the ocean. Mr. Schuyler gave a large amount of valuable information as to the comparative cost of river water and sewage irrigation in the vicinity of Los Angeles.

In addition to Mr. Bassell's paper, refer to Report of a board of engineers upon the disposal of the sewage of Los Angeles, etc., 1889, Eng. News, Vol. XXIX, February 23, 1893, and Sewage Disposal in the United States.

tables, potatoes, etc., 50 acres. The farm is self-sustaining, cost for maintenance and revenue being each about $2,500 per annum.

The experience at Los Angeles and Pasadena seems to be conclusive that there is no valid objection to the use of sewage for the irrigation and growth of all kinds of agricultural products. It is apparently a question merely of proper application., As showing the immense advantage of sewage disposal in the vicinity of Pasadena, it may be mentioned that bare land is worth at least $100 an acre without water, while watered land is held at about $600 an acre. The Pasadena sewage farm originally cost $125 an acre, or a total, including some extra expenses, of about $40,000.[1]

Redding.—Population in 1890, 1,821. A separate sewerage system was built by the town in 1889. Bassett & Rouhey, of Sacramento, the contractors for the sewage work, entered into an agreement to dispose of the sewage for forty years. For this purpose they purchased a tract of about 100 acres of land and prepared a portion of it for the utilization of sewage by irrigation. The area selected is comparatively level, with the soil a sandy and gravelly loam 4 to 6 feet deep, underlain by gravel. The sewage is applied directly to the land, either by running in furrows between rows or by spreading over the surface, according to the special requirements of each crop. The chief crops raised are corn, asparagus, potatoes, turnips, beets, and other garden truck. It has also been used for orchards and nursery stock. When used in this manner the trees were irrigated between the rows.[2]

San Luis Obispo.—Population in 1890, 2,995. Plans for sewage disposal by broad irrigation and intermittent filtration were prepared about 1888. No information is at hand as to whether or not they have been carried out.[3]

Santa Rosa.—Population in 1890, 5,220. Complaints of the pollution of the creek into which the sewage of the town was originally discharged, followed by a lawsuit, led to the purchase by the city of 18 or 19 acres of land on which the sewage has been purified since about 1889. The farm is leased to tenants, who take care of the sewage as rental, using it for gardening purposes.

Stockton.—Population in 1890, 14,224. The sewage of this place is stated to be used for irrigating purposes, but to what extent is not known.

DOMINION OF CANADA.

Berlin.—Berlin is the county seat of Waterloo County, and according to the census of 1891 had a population of 7,425. The chief industries of the town are manufacturing establishments, among which are included a large tannery and a glue factory. A public water supply

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[1] Refer to Burr Bassell's paper in Jour. of Assoc. of Eng. Socs., Vol. XIX, August, 1897; and to Sewage Disposal in the United States.

[2] Refer to Sewage Disposal in the United States.

[3] Refer to Colonel Waring's Sewerage and Land Drainage, 1889.

was built in 1888. Construction of sewers began in 1892, and in March, 1893, the actual quantity of sewage was about 50,000 gallons per day, diluted by some 75,000 gallons of subsoil water, making a total of 125,000 gallons in all. A sewage farm was completed in the fall of 1892 and first brought into use in 1893. In January, 1893, the temperature of the sewage as it arrived at the farm was found to be 48° F. The farm is located a mile south of the closely built-up section of the town. A stream, with a summer flow of about 200 cubic feet per minute, passes through the farm and receives the effluent.

The field purchased by the town for sewage-disposal purposes has an area of 20 acres, about an acre of which is included in the stream. The total area aside from the stream can easily be used for sewage farming by slight grading, as the greatest elevation is only 3 feet above the end of the outfall sewer. The surface soil is loam or sand, and the subsoil is of gravelly clay.

The designing engineer recommended that Italian rye grass be raised on the two north divisions of the farm, and on the remainder mangolds and other root crops, onions, oats, and clover. On the lowlands bordering the stream it is proposed to raise osiers, they having been raised with profit in Brantford, where dependence is had upon the freshets of the Grand River for irrigation. It is stated that the farm is suitably arranged for every known system of irrigation and every variety of crops. This farm is interesting from the fact that, as at the Croyden-Beddington farm, no settling tank has been provided, preference being given to the application of the solid matter directly to the land, where it can be dug in or raked off, as may be found most desirable. When in the course of time the amount of sewage has increased so that it exceeds the capacity of the farm for disposal by broad irrigation, it is proposed to construct filter areas at the south end, where gravel may be obtained within reasonable distance. The 20 acres purchased cost $2,000, and the cost of grading and underdraining the 7 acres already prepared was about $3,000, the underdraining and grading having cost at this rate a little over $400 per acre.

The results of cropping at Berlin are stated to have been substantially as follows: In 1894, 2,000 cabbage plants were set on about one-half an acre of land, of which 1,500 grew to marketable heads and were sold at the usual market price of 3 cents each. The cabbages were irrigated regularly and grew well. No attempt was made to hoe around them or hill them up, the surface of the ground being left entirely smooth.

The cultivation of Italian rye grass at Berlin does not seem to have been successful. The rye-grass seed was sown broadcast and soon came up, covering the ground with a mass of roots which are stated to have very much retarded the absorption of sewage. This experiment was made on a filter bed in a manner quite different from the ordinary practice of rye-grass cropping abroad. A chief difficulty of this trial

appears to have been an improper preparation of the land, depressions being left into which the sewage settled and which soon became foul. Abroad, on the contrary, this crop is not raised on beds at all, but on land so prepared as to avoid pondage of the sewage; besides this, the amount of sewage applied is regulated to the necessities of the crop and to the quality of the land, whereas at Berlin, so far as can be learned, the sewage application was made without special reference to the conditions. Under these circumstances the failure at Berlin can apparently have no other significance than to illustrate an erroneous method of procedure.

In 1895 a large area was devoted to cabbage, but by reason of a late frost many of the plants were killed. Later the cabbages were reset and the seeds of onions, carrots, mangolds, corn, and beans were planted. These crops are stated to have all done well except the corn and beans. The following is a detailed statement of the sale of produce from the Berlin farm in 1895, as compiled from the proceedings of the committee of the town council in charge of the farm:

August, 1,217 heads cabbage, at 2½ cents	$30
September, 1,771 heads cabbage, at 2½ cents	44
October, 2,272 heads cabbage, at 2½ cents	57
October, 134 bushels carrots, at 15 cents	20
October, 648 bushels carrots, at 15 cents	97
Corn (failure)	7
Pease (not irrigated to any extent)	15
November, 1,350 heads cabbage, at 2½ cents	34
Total	304

In addition to the foregoing, 150 kegs of sauerkraut, of 50 pounds each, were made from cabbage not sold in the head. These were held at $3 per keg.

The mangolds yielded 648 bushels from one-half an acre, giving at this rate the enormous yield of 1,296 bushels per acre. Those raised were easily sold to farmers for feeding stock. The experience, so far as gained at Berlin, indicates that mangolds will stand very heavy dosing of sewage.[1]

In 1896, complaints having been made by the local board of health of Waterloo Township to the effect that the sewage of Berlin was creating a nuisance in Berlin Creek, the matter was investigated by a committee of the board, which reported in effect that the farm had been managed on more economical lines than was desirable, such misplaced economy being the chief cause of the nuisance complained of. From this point of view the committee of the Provincial board suggested that the town council and local board of health of Berlin be instructed to adopt sufficient and adequate means whereby the whole sewage of the town could be applied on the beds in succession and completely purified before flowing to the creek. After making several

[1] Refer to Eng. News, Vol. XXIX, April 6, 1893, and Vol. XXXV, June 11, 1896; and to Rept. Prov. Bd. Health, 1896.

other recommendations the committee concluded its report with the statement that the farm could be made productive without there being any reasonable ground for complaint.

Hamilton.—Purification works by chemical precipitation have been approved for this place by the Provincial Board of Health. In order to insure efficient operation, a committee of the Provincial board which examined the plans in October, 1896, reported that in its opinion the management of the works, when constructed, should be left to the care and supervision of the city engineer, who should also be made responsible for the subordinate engineer in charge. The committee believed that with such management an effluent can be poured into Hamilton Bay of a purity compatible with the best interests of the public health. The works are under construction at the present time.

London.—It is understood that plans for sewage disposal by intermittent filtration are about to be carried out at this place. The land selected for the disposal fields is sandy and stated to be well adapted for the purpose.

London Hospital.—The works at London Hospital were constructed in 1888 and 1889 under the general direction of the architect in chief of the Ontario department of public works.

Previous to the construction of the disposal works the sewage from the hospital debouched into a small stream tributary to the south branch of the Thames River, which flows through the city of London. The drainage area of this stream is so small that it becomes nearly dry during the summer. The population of the hospital is over 1,000, and the daily amount of sewage 60,000 gallons. It became necessary, therefore, that some method of disposal be used other than of allowing the flow of raw sewage into the brook. The plan as carried out involves the flow of sewage into a receiving tank, from which it is pumped, as required, onto the disposal area of 30 acres, situated not far away. The general method is intermittent filtration, supplemented by broad irrigation. For this purpose an area of about 5 acres at the highest portion of the disposal area was leveled and laid out in absorption ditches. The balance of the field has been provided with a main carrier and distribution ditches, for use as an irrigation area whenever the filtration area is overworked or whenever during the growing season the sewage can be profitably utilized thereon for crops.

The filtration area is divided into three sections, onto each of which the sewage is run for one day, thereby giving two days' rest for a section after each application. The details of this work may be found in various publications in regard to sewage disposal.

Ontario Agricultural College.—Sewage purification by treatment with porous carbon supplemented by filtration through land was carried out at this institution in 1889. The daily amount of sewage averages 3,000 gallons. On its way to the settling tank it receives about 12 pounds of ferozone precipitant daily, and is allowed to settle for twenty-four

hours. The effluent is discharged on the filtering ground, which consists of a flat bed of gravel, clay, and loam, 100 by 75 feet in area, divided into two beds, each of which receives on alternate days the sewage for twenty-four hours. These beds are underdrained with tile drains, laid to a depth of from 2½ to 3 feet.

Waterloo.—Waterloo is located 2 miles south of Berlin, the town described previously, with which it is connected by a tramway. The population in 1891 was 2,941. Sewage-disposal works by intermittent filtration were constructed at this place in 1895. For the final works provision has been made for ten filter areas. The soil is sand and gravel. Each bed is 132 by 200 feet, giving an area of 26,400 square feet per bed. This area also includes the embankments, so that the actual purification area is somewhat less. As at Berlin, the sewage will be delivered upon the land without a preliminary screening out of the solid matters, the experience so far gained at the neighboring town of Berlin having indicated that there is little or no necessity for screening. Up to April, 1896, the total expenditure was about $2,000. The cost of the land is stated at about $80 per acre.

Concluding the foregoing account of sewage-disposal plants in the United States and Canada, we wish to state again that in such extreme condensation as is needful in a paper of this kind many important details are necessarily omitted. Complete descriptions of these works would require several hundred pages.

PUBLICATIONS RELATING TO SEWAGE UTILIZATION AND DISPOSAL.

The following books, pamphlets, reports, etc., are in the author's collection and have been consulted frequently in discussing questions of sewage utilization and disposal. There is no pretense to completeness in this list, including, as it does, only such as have been brought together without special effort. The books here included are a fairly good beginning for a library of sewage utilization and disposal and some of the more important cognate questions.

Adams (Julius W.). Sewers and drains in populous districts. 8vo. New York, 1880.

Contains short chapter on sewage disposal.

American Public Health Association, Proceedings of.

American Society of Civil Engineers, Transactions of.

Association of Engineering Societies, Journal of.

Association of Municipal and Sanitary Engineers and Surveyors, Proceedings of. Vols. I–XXI.

Contain a large number of valuable practical papers on sewerage, sewage disposal, and river pollution in England, as prepared by the engineers of the various works. Many of these papers are indispensable to anyone who wishes to study the question from a practical point of view.

Austin (Henry). Report on the means of deodorizing and utilizing the sewage of towns. Paper; 8vo. London, 1857.

Discusses a large number of the more important questions in sewage utilization in such a way as to be of great value to the student of the present day.

Backhouse (Benjamin). An account of Liernur's sewerage system in its present state of development based upon personal inquiry. By the chairman of the city of Sydney Improvement Board. Pamphlet; 8vo. London, 1887.

Baker (Henry B.). Report on best method of disposition of excreta and waste matters, at Harbor Point, Michigan.

Baker (M. N.). Sewage purification in America. Paper; 12mo. New York, 1893.

Baker (M. N.). Sewerage and sewage purification. 16mo. New York, 1896.

Baumeister (R.). The cleaning and sewerage of cities—sewerage, sewage disposal, street cleaning. Translation; 8vo. New York, 1891.

A concise statement of the German views on sewerage, sewage disposal, and street cleaning. Contains illustrations and is especially valuable for the reader who wishes to survey the whole field of the German view without reading a large number of works. As remarked in the introduction, prepared by Rudolph Hering, the American reader should remember that this work was prepared primarily for German engineers and for the conditions prevalent in the German Empire.

Birmingham sewage inquiry. 8vo. Birmingham and London, 1871.

This report contains a very thorough review of sewage purification as it existed in 1871, together with description and cuts of the pail system as used in Liverpool, Manchester, Rochdale, Birmingham, etc. The reader should remember, however, in reading the old reports, that many of the appliances which are illustrated have been improved within recent dates, and that the statements and illustrations can only be safely taken after one has obtained full knowledge of the subject and consequent power of selection.

Birmingham system of refuse disposal. Printed by order of the Birmingham Health Committee. Pamphlet; 8vo. Birmingham, 1893.

Blythe (A. Wynter). A manual of public health. 8vo. London, 1890.

Blythe (A. Wynter). Lectures on sanitary law. 8vo. London, 1893.

Contains twelve lectures on sanitary law delivered by the author at the College of Medicine as part of the usual course of instruction in sanitary science. Examples of by-laws relating to offensive trades, the law relating to adulteration, etc., are given in the appendix.

Boston main drainage works. 8vo. Boston, 1885.

Contains a full account of the construction of the main drainage works of the city of Boston, where, by reason of the nearness of the ocean, it was deemed preferable to dispose of the city sewage by discharge at high tide into the waters of the lower harbor.

Boulnois (H. Percy). Municipal and sanitary engineer's handbook. 8vo. London, 1893.

Brookman (F. W.). Utilization of town refuse at Rochdale. Reprint from the Journal of Society of Chemical Industry, April 30, 1895. London, 1895.

Buck. Treatise on hygiene and public health. 2 vols. 8vo. New York, 1879.

Burke (N. R.). A handbook of sewage utilization. 12mo. London, 1872.

Burn (R. Scott). Outlines of modern farming. 6th edition. 12mo. London, 1888.

Treats extensively among other subjects of the utilization of town sewage, irrigation, etc.

Callis (Robert W.). Lectures on sewers. Large 8vo. London, 1686.

Contains a series of lectures on sewers as delivered by the author, at Grace Inn, in August, 1622.

Chandler (C. F.). Report on the waters of the Hudson River, made to the water commissioners in the city of Albany. Paper; 8vo. New York, 1885.

The author, in 1885, takes the ground that the Hudson River was at the time a proper water supply for the city of Albany.

Chicago drainage and water supply. Preliminary report of a commission consisting of Rudolph Hering, Benezette Williams, and Samuel G. Artingstall. Paper; 8vo. Chicago, 1887.

Clippart (John H.). The principles and practice of land drainage. 3d edition. 12mo. Cincinnati, 1888.

Connecticut State Board of Health, 1884 to 1895, inclusive.

These reports contain a large amount of original work on pollution of water supplies and stream pollution generally as performed under the direction of the State board of health during the period included.

Cooley (Lyman E.). The Lakes and Gulf waterway as related to the Chicago sanitary problem. Paper; large 8vo. Chicago.

Coplin (W. M. L. and Bevan D.). A manual of practical hygiene. 8vo. Philadelphia, 1893.

Corfield (W. H.). The treatment and utilization of sewage. 3d edition, revised and enlarged by the author and Louis C. Parks. 8vo. London, 1887.

In this work the question of sewage utilization is examined at considerable length, and many useful conclusions are reached.

Crimp (W. Santo). Sewage disposal works. A guide to the construction of works for the prevention of pollution by sewage of rivers and estuaries. 1st edition. 8vo. London, 1890. 2d edition. London, 1894.

Contains descriptions up to date of a large number of the more important English sewage disposal works.

Dempsey (G. D.). Drainage of lands, towns, and buildings. Revised edition with large additions of recent practices in drainage engineering, by D. Kinnear Clark. 12mo. London, 1890.

Denton (J. Bailey). Sanitary works and sewage utilization. Paper; 8vo. London, 1869.

Denton (J. Bailey). Ten years' experience in works of intermittent downward filtration. 8vo. London.

Dibdin (W. J.). Report of experiments on the filtration of sewage effluent (from the London main drainage works) during the years 1892–1895, inclusive. Paper; 4to. London, 1895.

Engineering News. From 1892 to 1897, inclusive.

This journal contains more or less complete descriptions of the more interesting and important of the American works.

Engineering Record.

This journal has published a vast amount of information in regard to sewerage and sewage disposal both at home and abroad, and in 1889 published an index to matter pertaining to sewerage and sewage disposal which had appeared in Vols. V to XVII (December, 1881–June, 1888). There has also appeared a large amount of matter in the volumes from XVIII to XXXIV (the current volume).

Framingham, Massachusetts. System of sewage disposal. A report of a committee on drainage and sewerage and construction of a sewerage system. Statement in detail of cost of construction, plans, etc. 8vo. South Framingham, 1889.

Frankland (Percy and Mrs. Percy). Micro organisms in water, their significance, identification, and removal. 8vo. London, 1894.

Contains a statement of the relation of sewage-polluted water to disease.

French (Henry F.). Farm drainage. The principles, practice, and methods of draining land, etc. 12mo. New York, 1884.

Gerhardt (William Paul). The disposal of sewage at isolated country houses. Paper; 8vo. Providence, 1890.

Gerhardt (William Paul). The disposal of household wastes. 16mo. New York, 1890.

Gerhardt (William Paul). Sanitary engineering. Reprint from the Journal of the Franklin Institute, June–August, 1895. Paper; 8vo. Philadelphia, 1895.

Gray (Samuel M.). Proposed plan of a sewerage system for the disposal of the sewage of the city of Providence. Made by order of the city council of the city of Providence. Paper; 8vo. Providence, 1884.

Contains an account of a large number of sewage purification plants abroad as visited by Mr. Gray, together with recommendations for the partial purification of sewage of Providence by chemical treatment, followed by its discharge into tide water at a point where it could not become a nuisance along the adjacent beaches.

Gray (Samuel M.). Report showing location and size of the main intercepting sewers of the city of Providence and other information called for by the common council by resolutions of various dates in 1886. Paper; 8vo. Providence, 1886.

Griffiths (A. B.). A treatise on manures. 12mo. London, 1889.

Hall (William Hammond). Irrigation in California. 2 vols. 8vo. San Francisco, 1888, 1889. A report on irrigation in California as made by the State engineer.

A good text-book of American irrigation practice.

Harris (Joseph). Talks on manures. New and enlarged edition. 12mo. New York, 1888.

Hawkshaw (Sir John). Report as commissioner appointed to inquire as to the purification of the river Clyde. Paper; 4to. London, 1876.

Contains information as to the pollution of the river Clyde and its tributaries as they existed in 1876.

Hazen (Allen). Filtration of public water supplies. 8vo. New York, 1895.

Contains data as to quality of filtering material, construction of filters, etc.

Hazen (Allen). A practical plan for sand filtration as a means of securing a better water supply to the city of Philadelphia. Report to the Woman's Health Protective Association of Philadelphia. Paper; 8vo. 10 pp. 1896.

Health in country homes. The disposal of sewage. A series of articles reprinted from the New York Evening Post. Paper; 8vo.

Health of Towns Commission. This commission made two reports—the first, 1844, published in two 8vo. vols.; the second, in 1845, also in two 8vo. vols.

These two reports may be taken as the beginning of sanitary science in England and in the civilized world generally. These reports should be studied by any person wishing to study the whole subject of sewage utilization, by way of showing the magnitude of the evil which has been combatted and greatly mitigated since 1844.

Hill (John W.). Sewage disposal and water supply. A paper read before the Ohio Society of Surveyors and Civil Engineers, January 18, 1893. Reprinted for private circulation. Paper; 8vo.

Hill (John W.). Water supplies for eight cities in relation to typhoid-fever rates. An address before the Society of Municipal Improvements, Chicago, October 9, 1896. Paper; 12mo. 8 pp. Cincinnati, 1896.

Hill (John W.). The hygiene of water. A lecture delivered before the Teachers' Institute, Cincinnati, Ohio, September 11, 1896. Reprint from the Dietetic and Hygienic Gazette, October, 1896. Paper; small 4to. 10 pp. 1896.

Hutchinson (Christopher Clarke). On the disposal of sewage sludge. A paper read before the Society of Chemical Industry, February 4, 1884. Paper; 8vo. London, 1884.

Institution of Civil Engineers, Proceedings of. Vols. I–CXX. 8vo. London, 1838–1895.

Contain a large amount of information on river pollution and sewage deodorization, filtration, interception, irrigation, manure, precipitation, and sewage utilization generally. Detailed subject indexes have been issued from Vols. I-LVIII and from Vols. LIX–CXVIII, to which reference may be made for nearly every phase of the subject as discussed in England for the last forty to fifty years.

Johnson (Samuel W.). How crops feed. A treatise on the atmosphere and the soil as related to the growth of agricultural plants. 12mo. New York, 1890.

Johnson (Samuel W.). How crops grow. A treatise on the chemical composition, structure, and life of the plant. 12mo. New York, 1890.

Jones (Charles). Refuse destructors. 2d edition. 8vo. London, 1894.

Contains detailed information as to the result of garbage destruction by fire, as well as a paper on the utilization of town refuse for power production, by Thomas Tomlinson.

Kiersted (Wyncoop). A discussion of the prevailing theories and practice relating to sewage disposal. 12mo. New York, 1894.

The author believes that the rivers of the country are, on the whole, the natural place for disposing of sewage. In his view the natural forces of nitrification will purify the sewage in streams somewhat the same as on land.

Kinnett (C. T.). Nature's hygiene. A systematic manual of natural hygiene. 4th edition. 8vo. London, 1894.

Kropp (Charles Frederick). The sewage question. A general review of all systems and methods. 8vo. London, 1867.

Especially devoted to showing the superiority of the pneumatic system of Capt. Charles Liernur.

Kuichling (E.). Report on the proposed trunk sewer for the east side of the city of Rochester, New York. Pamphlet; 8vo. Rochester, 1889.

Contains a résumé of the various methods of sewage disposal and leans to the conclusion that for the conditions existing in Rochester a chemical treatment would be preferable.

Latham (Baldwin). Sanitary engineering. A guide to the construction of works on sewerage and house drainage. 2d edition. 8vo. London, 1878.

This work was reprinted by Engineering News in 1877.

Lawes (J. Parry). Reports of sewer air investigations, as made to the London County Council. Paper. London, 1894.

Leffmann (Henry) and **Beam** (William). Examination of water for sanitation and domestic purposes. 12mo. Philadelphia, 1889.

Lehmann (K. B.). Methods of practical hygiene. 2 vols. 8vo. London, 1893.

Translated from the German by W. Crooks.

Local Government Board. Reports of the medical officer.

The reports of the medical officer of the privy council and local government board have contained for many years much information of interest and value relating to sewage purification and utilization. The student of the subject will find in these reports a vast amount of important matter. In the supplement to the report of the medical officer for 1891 may be found a study of enteric fever in the valley of the river Lee. In the supplement to the report for 1887 may be found papers giving full statistics of diarrhea and diphtheria in England. The first of these is a report by Dr. Ballard of the cause of the mortality from diarrhea which is observed principally in the summer seasons of the year in English communities, and the second is a statistical study by Dr. Longstaff on the geographical distribution of diphtheria in England and Wales. Dr. Ballard's statistical inquiry included the years from 1880 to 1888, while Dr. Longstaff's included the twenty-six years ending with 1880. The relation of these two diseases to sanitary conditions is set forth in many tables and diagrams with great clearness.

Lowcock (Richard Sidney). Experiments on the filtration of sewage. Excerpt from Proceedings Institution Civil Engineers, Vol. CXV. Paper; 8vo. London, 1893.

Mason (William P.). Water supply, chemical and sanitary. 8vo. New York, 1896.

Contains an excellent statement of drinking water as affected by sewage pollution in its relations to disease.

Massachusetts Drainage Commission, Report of. 8vo. Boston, 1886.

This commission was authorized by the Massachusetts legislature to consider and report systems of drainage for the Mystic, Blackstone, and Charles river valleys. In 1885 a report of great value was submitted, in which questions of stream pollution and sewage disposal are discussed at length. The engineer of the commission, Elliot C. Clark, also submitted a report in which he gave the details of the problem of prevention of stream pollution and methods of sewage purification as applied to the river valleys named. One of the best of the early American reports.

Massachusetts State Board of Health, Reports of.

This splendid series of sanitary reports now includes 27 volumes of annual reports and 2 special reports on the purification of sewage and water and on the examination of water supplies, besides special reports on the sewerage of the Mystic and Charles river valleys, and on the Metropolitan water supply of Boston, making 31 volumes in all. These are indispensable to any person who desires to study thoroughly the subject of sewage purification and utilization in the United States. Stream pollution, sewerage, and sewage disposal were first discussed in the Fourth Annual Report, and have been discussed in some phase ever since. In the Nineteenth Annual Report may be found the preliminary account of the special experiments on intermittent filtration carried out by the board at Lawrence.

Menzies (William). A treatise on the sanitary management and utilization of sewage. Large 8vo. London, 1865.

Metropolitan sewage discharge. Report of Royal Commissioners. 4 vols. of reports; minutes of evidence; appendixes, etc. 4to. London, 1884, 1885.

Presents every phase of question of disposal of sewage of London as it existed twelve years ago.

Metropolitan water supply, Report of Royal Commission on. 6 vols. General report; minutes of evidence; appendixes; index; plans, etc. 4to. London, 1893.

The most recent and extensive information as to pollution of streams and its effect on the water supply of the metropolis as applied to the rivers Thames and Lee, from which that supply is drawn.

Miles (Manly). Silos, ensilage, and silage. 12mo. New York, 1892.

A practical treatise on the construction of silos and the practical working of the process of ensilage.

Milwaukee, Wisconsin. Report of the Commission of Engineers on the collection and final disposal of the sewage and on the water supply of the city of Milwaukee. Paper; 8vo. Milwaukee, 1889.

Monson (Edward). The advantage of a separate system of drainage. Paper; 8vo. London, 1875.

Monson (Edward). Metropolitan sewage and what to do with it; a scheme of sewage disposal for the metropolis and the author's scheme of drainage for the lower Thames Valley, etc., the whole being a complete system of sewage clarification and purification. 8vo. London, 1883.

Moore (E. C. S.). Sanitary engineering. Occasional papers, Royal Engineers' Institute, being part of the professional papers of the Corps of Royal Engineers, Vol. XVII. 8vo. London, 1892.

Contains concise notes on various matters relating to sewerage and sewage disposal, as prepared specially for the use of the Royal Engineers.

Munroe (John M. H.). Composition and manurial value of filtered pressed sewage sludge. Reprint from the Journal of the Society of Chemical Industry, January 29, 1885. Manchester, 1885.

National Board of Health, Report for 1881.

This volume contains a report of the results of an examination made in 1880 of several sewerage works in Europe by Rudolph Hering. The information given, while extremely valuable in 1880, is of less interest now, by reason of being more recently covered. Mr. Hering gives a literature list which is still of value.

New Jersey State Board of Health, Vols. I–XVIII.

Contains information as to sewage-disposal works and stream pollution in New Jersey.

New York State Board of Health, Reports 1 to 16.

A large amount of information as to sewage disposal and stream pollution may be found in these reports, together with the detail plans of sewage-disposal plants thus far designed for towns in New York.

Palmberg (Albert). A treatise on public health and its applications in different European countries. Translated from the French. Edited by Arthur Newsholme. 8vo. London, 1893.

Contains a review of sanitary administration and legislation in the principal European countries.

Parks (Edward A.). A manual of practical hygiene. Edited by De Chaumont, with an appendix, giving the American practice in matters relating to hygiene, prepared by and under the supervision of Frederick N. Owen. 2 vols. Large 8vo. New York, 1884. From the last London edition.

Parks (Louis C.). Hygiene and public health. 12mo. Philadelphia, 1889.

Pennsylvania State Board of Health, Vols. I–X.

Contain many general discussions on stream pollution, sewerage, and sewage disposal.

Philadelphia Water Department, Annual Reports of the Chief Engineer, 1883 to 1886, inclusive.

These reports contain the results of an investigation as to the pollution of the water supply of the city of Philadelphia by sewage, together with the reports on additional supplies from unpolluted or nearly unpolluted sources, with methods of preventing pollution, etc. They may be referred to for much valuable information on the general question of pollution of streams and its attendant evils.

Philbrick (Edward S.). American sanitary engineering. 8vo. New York, 1881.

Philbrick (Edward S.). The disposal of sewage in suburban residences. Paper; 12mo. New York, 1883.

Platt (S. Sidney). Description of the sewage-disposal works at Roch Mills, Rochdale, England. Paper; 12mo. 4 pp. Rochdale, 1896.

Pollution of water supplies. Report of a committee of the American Public Health Association. Read at the annual meeting at Milwaukee, November 20–23, 1888. Paper; 8vo. Concord, 1889.

Provincial Board of Health of Ontario. Reports 1–4.

Contain information as to sewage-disposal works and stream pollution in the Dominion of Canada.

Rafter (George W.) and **Baker** (M. N.). Sewage disposal in the United States. 8vo. New York, 1893.

This work is dedicated to the health and prosperity of American cities, and contains descriptions and references to practically all the sewage-disposal works in the United States up to the summer of 1893.

Rauch (John H.). The sanitary problems of Chicago, past and present. Reprint from the Second Annual Report of the Illinois State Board of Health. Paper; 8vo.

Reeves (R. Harris). Sewer ventilation and sewage treatment. 12mo. London, 1889.

Contains description of special methods of chemical treatment and ventilation designed by the author.

Rivers Pollution Commission (first commission). 5 vols. 4to. London, 1866, 1867.

This commission made three reports. The first report deals generally with the best methods of preventing the pollution of rivers, with special reference to the conditions prevailing at that time on the river Thames. The second report deals with the river Lee. The third report deals with the rivers Ayr and Calder.

Rivers Pollution Commission (second commission). Report of the commissioners appointed in 1868 to inquire into the best means of preventing the pollution of rivers. 10 vols. 4to. London, 1870, 1871, 1872, 1874.

This commission made six reports in all. The first report, in two volumes, treats of the pollution of the basin of the rivers Mersey and Ribble and of the best means of preventing pollution therein. The second report is taken up with a description of the A, B, C process of treating sewage. The third report, in two volumes, discusses the pollution arising from the woolen manufacture and processes connected therewith. The fourth report treats of the pollution of the rivers of Scotland, and gives special consideration, among other subjects, to the pollution arising from paper-mill wastes, etc. The fifth report, in two volumes, treats of the pollution arising from mining operations and metal manufactures. The sixth report, in one volume, treats of the general subject of domestic water supply of Great Britain. In this report Dr. Edwin Franklin, the chemist member of the commission, has here worked out in detail the method of water analysis which he designated as the combustion method. A large amount of information about water supplies from cultivated and uncultivated areas and the contamination of water from manured and unmanured, cropped and uncropped land is given, the whole forming a vast body of sanitary information pertinent to present conditions.

Royal Sanitary Commission, Report of. Second report. 4to. London, 1871.

Contains a history of the English sanitary laws up to that date, with suggestions for new statute, etc.

Sanitary Institute, Transactions of. Vols. I–XII.

Contains many practical papers on sewerage and sewage disposal. 8vo. London.

Sewage disposal. Report of a committee appointed by the president of the local government board to inquire into the several modes of treating town sewage. Paper; 8vo. London, 1876.

Contains many details of sewerage work carried out in England to that date, with a large number of analyses of raw and effluent sewage at several sewage farms. In appendix No. 7 is given a list of a large number of patented processes for treating sewage and producing artificial manure therefrom, as taken out from between the years 1856 and 1875 inclusive. The report is also accompanied by a folio of plans, giving details of a number of the more interesting sewage-disposal works of that date.

Sewage disposal at Los Angeles, California. A report of the board of engineers upon the disposal of the sewage of Los Angeles city and its sewer system, presented to the mayor and common council of the city of Los Angeles, December 23, 1889. Paper; 8vo. 1889.

Contains the preliminary information as to sewage utilization at Los Angeles.

Sewage disposal at the London, Ontario, Asylum. Report of the Provincial Board of Health of Ontario. Paper; 8vo. Toronto, 1890.

Contains the report and detailed plans as submitted by Col. George E. Waring, jr.

Sewage disposal at the Rhode Island State institutions. Seventeenth Annual Report of the Board of State Charities and Corrections of Rhode Island, 1885. Paper; 8vo. Providence, 1886.

Contains the report and plans of Samuel M. Gray upon the disposal of the sewage of the State institutions at Cranston, Rhode Island.

Sewage disposal at the Rochester, Minnesota, State Hospital for the Insane. Sixth Biennial Report of the Trustees and Officers of the State Hospital, Rochester, Minnesota. 8vo. Minneapolis, 1890.

Contains report and detailed plans of the purification works at the Rochester Hospital.

Sewage farm competition of the Royal Agricultural Society of England. Report of judges appointed in the sewage farm competitions. Reprint from the journal of the Royal Agricultural Society. 8vo. London, 1880.

Sewage of the District of Columbia. Report by Rudolph Hering, Samuel M. Gray, and Frederick P. Stearns. Paper; 8vo. Washington, 1890.

Sewage of the Metropolis. Report from a select committee, ordered by the House of Commons to be printed July 14, 1864. Paper; 4to. London, 1864.

This committee was appointed specially to inquire into plans for dealing with the sewage of the metropolis (London) and other large towns with a view to its utilization in agriculture. The committee concluded that it is not only possible to utilize the sewage of towns, but that such an undertaking may be made to result in pecuniary advantage to the rate payers of the towns whose sewage is thus utilized. A large amount of evidence was taken by calling before the committee a number of the eminent engineers and English sanitarians of the day.

Sewage of Towns, Report from the select committee on. Two reports, in 2 volumes. First report ordered to be printed April 10, 1862, and the second report April 29, 1862. 4to. London, 1882.

Sewage of Towns Commission. Three reports. 8vo. London, 1858, 1861, 1865.

These reports contain the detail of elaborate investigations made by a royal commission appointed to inquire into the best mode of distributing the sewage of towns and applying it to beneficial and profitable uses. Elaborate cultivation and feeding experiments were pursued, extending over a period of several years, the results of which were presented in great detail in the second and third reports. In the appendix to the first report may be found an account of a visit made by a committee of the commission to Milan, Italy, for the purpose of examining the sewage utilization works which had been carried out at that place. This committee reported under date of December, 1857, that the experience of the irrigation around Milan adds a striking proof to those already obtained as to the value in agriculture of a command of pure water and of the immense increase of that value obtained by the addition of sewage combined with the higher temperature derived by the liquid in its passage through the town.

Sewage purification. Return of the particulars of the means adopted by local authorities for the purification or disposal of sewage, as made to the municipal authorities of the borough of Rochdale. 4to. 1872.

Contains details as to the population of towns, area of sewage farms or disposal areas, average rainfall of district, cost of land, number of years in operation, method of managing farm, information as to nuisances from effluent, etc. Also contains the particulars as to a large number of precipitating plants in operation in England in 1872.

Sewage treatment at the Barking and Crossness outfalls. Report by the engineer for the year 1894, ordered printed by the main drainage committee July 11, 1895. The same for the year 1893, ordered printed by the main drainage committee May 31, 1894. Five pamphlets in all. 4to. London.

Sewage utilization at the State Lunatic Asylum at Worcester, Massachusetts. Forty-seventh Annual Report of the Trustees, for the year ending September 30, 1879. Paper; 8vo. Boston, 1880.

Contains plans of the sewage utilization works as carried out in 1876 and as still in successful use at that institution.

Shedd (J. Herbert). Report on sewerage of the city of Providence. Paper; 8vo. Providence, 1874.

Slater (J. W.). Sewage treatment, purification, and utilization. 12mo. London, 1888.

Largely devoted to description and discussion of special processes of chemical purification. Contains a list of patents granted for sewage purification processes by chemical treatment, from 1886, inclusive. The total number of patents listed in that period is given at page 454, of which 11 have been taken out by the author of the work.

Snow (F. Herbert). Report on sewer assessments. Paper; 8vo. Brockton, 1894.

Staley (Cady) and **Pierson** (George S.). A separate system of sewerage, its theory and construction. Second edition; 8vo. New York, 1892.

Contains short chapter on sewage disposal.

Storer (F. H.). Agriculture in some of its relations with chemistry. 2 vols. 8vo. New York, 1888.

Professor Storer's two volumes contain a survey of the whole field of scientific agriculture to date. As regards sewage utilization, following the English views of ten to fifteen years ago, he is disposed to say that it can not be made commercially successful. His work should be consulted by every person interested in the subject.

Tidy (C. Meynott). The treatment of sewage. 16mo. New York, 1887.

Tieman (F.) and **Gartner** (A.). Die chemische und mikroskopisch-bakteriologische Untersuchung des Wassers. Paper; 8vo. Braunschweig, 1889.

Tottenham Local Board of Health. A report on the disposal of sewage of the district, made by the Tottenham local board in May, 1870. 8vo. London, 1870.

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The French literature on sewage disposal is quite extensive, but is necessarily omitted because of lack of space. A number of new works and reports in English, which have appeared since the compilation of this list, are also omitted because of lack of space.

INDEX.

Albion, N. Y., sewage disposal at..... 67
Alliance, Ohio, sewage disposal at..... 75
Altoona, Pa., sewage disposal at..... 72–73
Amherst, Mass., sewage disposal at..... 42
Analyses of sewage..... 26–28, 44, 54, 63, 75
Andover, Mass., sewage disposal at..... 56
Arizona, sewage disposal in..... 82
Ashland, Wis., typhoid fever at..... 39–40
Atlantic City, N. J., sewage disposal at.. 69–70
Augusta, Me., sewage disposal at..... 41
Batavia, N. Y., sewage disposal at..... 65
Bath, N. Y., sewage disposal at..... 65
Berlin, Canada, sewage disposal at..... 85–88
Blackstone River, Massachusetts, pollution of..... 54
Boston, Mass., water supply of..... 47–50
Braintree, Mass., sewage disposal at..... 56
Brewsters, N. Y., sewage disposal at..... 62
Bridgewater, Mass., sewage disposal at.. 57
Bristol, Conn., sewage disposal at..... 59–60
Brockton, Mass., sewage disposal at..... 42–45
Brooklyn, N. Y., sewage disposal at..... 62–63
Buffalo, N. Y., typhoid fever at..... 39
California, sewage disposal in..... 82–85
Canada, sewage disposal in..... 85–89
Canton, Ohio, sewage disposal at..... 75–76
Central Falls, R. I., sewage disposal at... 57–58
Chautauqua, N. Y., sewage disposal at... 63–64
Chicago, Ill., sewage disposal at.... 38, 40–41, 79
Cobleskill, N. Y., sewage disposal at..... 67
Colorado, sewage disposal in 80–81
Colorado Springs, Colo., sewage disposal at..... 80
Concord, Mass., sewage disposal at..... 48, 56
Concord, N. H., sewage disposal at..... 41–42
Connecticut, sewage disposal in.... 20–22, 59–62
Cortland, N. Y., sewage disposal at 67
Cost of sewage-disposal works..... 63, 76
Cranston, R. I., sewage disposal at..... 59
Crops, use of sewage on various..... 45
Danbury, Conn., sewage disposal at..... 60
Danvers, Mass., sewage disposal at..... 56
Duluth, Minn., typhoid fever at..... 40
Dyestuffs, purification of..... 29–30
East Orange, N. J., sewage disposal at... 70
East Taunton, Mass., sewage purification at..... 23–24
England, origin of sewage irrigation in.. 13
character of sewage in..... 14–15
Essex Fells, N. J., sewage disposal at..... 70
Far Rockaway, N. Y., sewage disposal at. 64
Fertilizers, value of..... 37–38
Filter materials, experiments with..... 31–34
Flatbush, N. Y., sewage disposal at..... 67
Fonda, N. Y., sewage disposal at..... 68
Fort Plain, N. Y., sewage disposal at..... 67
Fostoria, Ohio, sewage disposal at..... 76
Foxboro, Mass., sewage disposal at..... 56
Fresno, Cal., sewage disposal at..... 82
Fulton, N. Y., sewage disposal at..... 68
Gardner, Mass., sewage disposal at..... 45–46
Genesee River, pollution of..... 71
Gowanda, N. Y., sewage disposal at..... 68
Great Lakes, pollution of..... 36–41
Greenfield, Mass., sewage disposal at..... 46
Hamilton, Canada, sewage disposal at... 88
Hastings, Nebr., sewage disposal at..... 80
Helena, Mont., sewage disposal at..... 81
Hemlock Lake, New York, pollution of.. 64–65
Herkimer, N. Y., sewage disposal at..... 68
Holly, N. Y., sewage disposal at 68
Hyde Park, Mass., sewage purification at. 23
Ilion, N. Y., sewage disposal at..... 68
Illinois, sewage disposal in..... 77–79
Intermittent filtration, purification by.. 34
Jamestown, N. Y., sewage disposal at.... 68
Kenton, Ohio, sewage purification at.... 25–26
Lake Calumet, Illinois, pollution of ... 77–79
Lake Cochituate, Massachusetts, pollution of..... 50–52
Lake Michigan, pollution of 38
Lake Wauremaug, Connecticut, pollution of..... 60
Lawrence, Mass., experiments at..... 15, 30–35
Lawrenceville School, New Jersey, sewage disposal at..... 70
Leadville, Colo., sewage disposal at..... 80–81
Leicester, Mass., sewage disposal at..... 56
Lenox, Mass., sewage disposal at..... 46
Litchfield, Conn., sewage disposal at 60
London, Canada, sewage disposal at..... 88
Long Branch, N. J., sewage disposal at.. 70
Lorain, Ohio, typhoid fever at 39
Los Angeles, Cal., sewage disposal at.... 82–84
Lyons, N. Y., sewage disposal at..... 68
Maine, sewage disposal in 41
Manchester, Conn., sewage disposal at... 60
Manufacturing waste, purification of 27–35
Marlboro, Mass., sewage disposal at..... 46–47
Massachusetts, sewage disposal in..... 17–20, 23–24, 26, 42–57
Massachusetts board of health, experiments of 15, 27–35
cited..... 17-18, 27, 34, 41, 44, 54–55

	Page.
Massachusetts drainage commission cited	22
Medfield, Mass., sewage disposal at	48, 57
Menominee River, Wisconsin, pollution of	24–25
Menominee Valley, Wisconsin, sewage disposal in	79
Meriden, Conn., sewage disposal at	20–21, 61–62
Michigan, sewage disposal in	77
Millbury, Mass., sewage purification at	23
Milwaukee, Wis., sewage purification near	24–25, 88
Minnesota, sewage disposal in	79–80
Montana, sewage disposal in	81
Morris Plains Asylum, New Jersey, sewage disposal at	70–71
Mount Vernon, N. Y., sewage disposal at	69
Mystic Valley, Massachusetts, sewage disposal in	48–49
Natick, Mass., sewage disposal at	50–51
Nebraska, sewage disposal in	80
Neponset River, Massachusetts, pollution of	18–20
New Britain, Conn., stream pollution at	21
New Hampshire, sewage disposal in	41–42
New Jersey, sewage disposal in	15–17, 69–72
New Rochelle, N. Y., sewage disposal at	64
New York, sewage disposal in	62–69
Newell, F. H., letter of transmittal by	9
Norfolk County, Mass., sewage disposal in	51
Norristown, Pa., sewage disposal at	73
North Brookfield, Mass., sewage disposal at	51
North Tarrytown, Mass., sewage disposal at	69
Norwood, Mass., experiments at	28
Oberlin, Ohio, sewage disposal at	76–77
Ohio, sewage disposal in	25–26, 75–77
Ohio board of health cited	25
Oneida, N. Y., sewage disposal at	69
Ontario Agricultural College, Canada, sewage disposal at	88–89
Paper-mill wastes, purification of	27
Paris, Tex., sewage disposal at	74–75
Pasadena, Cal., sewage disposal at	84–85
Passaic River, New Jersey, pollution of	15–17
Pawtucket, R. I., sewage disposal at	58–59
Pegan Brook, Massachusetts, pollution of	50, 52
Pelham Manor, N. Y., sewage disposal at	69
Pennsylvania, sewage disposal in	72–74
Phœnix, Ariz., sewage disposal at	82
Pittsfield, Mass., sewage disposal at	57
Plainfield, N. J., sewage disposal at	71
Poughkeepsie, N. Y., sewage disposal near	65–67
Princeton, N. J., sewage disposal at	71
Providence, R. I., sewage disposal at	22–23, 59
Publications relating to sewage disposal, list of	89–98
Pullman, Ill., sewage disposal at	77
Quinnipiac River, Connecticut, pollution of	20–22
Reading, Pa., sewage disposal at	73–74
Redding, Cal., sewage disposal at	85
Rhode Island, sewage disposal in	22–23, 57–59
Rivers Pollution Commission of England cited	14, 22, 29
Rochester, Minn., sewage disposal at	79
Rochester, N. Y., sewage disposal at	69
Rockingham County, N. H., sewage disposal in	42
St. Johns, Mich., sewage disposal at	77
Salt Lake City, Utah, sewage disposal at	81–82
San Antonio, Tex., sewage disposal at	75
San Luis Obispo, Cal., sewage disposal at	85
Sands, mechanical analyses of	31–34
Santa Rosa, Cal., sewage disposal at	85
Saylesville, R. I., sewage purification at	23
Scioto River, pollution of	25–26
Sherborn Prison, Massachusetts, sewage disposal at	52
South Framingham, Mass., sewage disposal at	52–53
Spencer, Mass., sewage disposal at	57
Stockton, Cal., sewage disposal at	85
Stoneham, Mass., sewage purification at	26
Stream pollution, discussion of	15–22
Sudbury River, Massachusetts, pollution of	19, 46–47
Summit, N. J., sewage disposal at	71–72
Tannery wastes, purification of	28–29
Taunton River, Massachusetts, pollution of	24
Temple, Tex., sewage disposal at	75
Tewksbury, Mass., sewage disposal at	57
Texas, sewage disposal in	74–75
Trinidad, Colo., sewage disposal at	81
Typhoid fever, occurrence of	38–41
United States, distribution of sewage-disposal plants in	11–13
Utah, sewage disposal in	81–83
Vassar College, New York, sewage disposal at	65–67
Wakefield, Mass., sewage disposal at	57
Wallingford, Conn., stream pollution at	21
Waltham, Mass., sewage disposal at	52
Waterbury, Conn., sewage disposal at	21–22, 62
Waterloo, Canada, sewage disposal at	89
Wayne, Pa., sewage disposal at	74
Wayne County, Mich., sewage disposal in	77
Wellesley College, Massachusetts, sewage disposal at	53
West River, Rhode Island, pollution of	22–23
West Virginia, sewage disposal in	74
Westboro, Mass., sewage disposal at	53
Westfield, N. J., sewage disposal at	72
Weston, W. Va., sewage disposal at	74
Williams Bridge, N. Y., sewage disposal at	69
Winchester, Mass., sewage purification at	23
Windsor, Ontario, typhoid fever at	39
Wisconsin, sewage disposal in	24–25, 79
Wisconsin board of health, cited	24
Wool-scouring wastes, purification of	27–28
Woonsocket, R. I., sewage disposal at	59
Worcester, Mass., sewage disposal at	53–56
Yalesville, Conn., stream pollution at	21

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DEPARTMENT OF THE INTERIOR

WATER-SUPPLY

AND

IRRIGATION PAPERS

OF THE

UNITED STATES GEOLOGICAL SURVEY

No. 23

WATER-RIGHT PROBLEMS OF THE BIGHORN MOUNTAINS.—MEAD

WASHINGTON
GOVERNMENT PRINTING OFFICE
1899

UNITED STATES GEOLOGICAL SURVEY

CHARLES D. WALCOTT, DIRECTOR

WATER-RIGHT PROBLEMS

OF THE

BIGHORN MOUNTAINS

BY

ELWOOD MEAD

WASHINGTON

GOVERNMENT PRINTING OFFICE

1899

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CONTENTS.

	Page.
Letter of transmittal	9
Introduction	11
Number of appropriations and acreage reclaimed	12
Value of water rights	13
Board of control	14
Water divisions and districts	17
Appropriations in Division II	18
District 2, Crazy Woman Creek	18
Decree of 1889	18
Objections to the decree	21
Excessive amounts claimed	24
District 3	28
Flow of Clear Creek	28
Early rights and their adjudication	31
Diversion across divides	32
Prairie Dog Creek	35
Summary of rights to water	36
Allowance for loss of water in transmission	38
Ownership in ditch not necessary to the acquirement of a water right	40
District 4	43
District 5	45
Little Tongue River	49
Appropriations in Division III	50
District 6	50
Order establishing priorities and amounts of appropriations of water from No Wood River and its tributaries	50
Reservoirs	55
Administrative questions	58
Index	61

ILLUSTRATIONS.

Page.

PLATE I.—*A*, North side of Cloud Peak; *B*, Bighorn Mountains as seen from Buffalo, Wyoming 11
II.—Piney Creek below outlet of Cloud Peak Lake 32
III.—Reservoir sites on Piney Creek: *A*, At Elk Lake; *B*, At Mead Lake 34
IV.—North slope of Massacre Hill, illustrating erosion in ditches from Piney Creek 36
V.—Timber flume in the canyon of Tongue River 44
VI.—Beginning of dam at north end of Dome Lake reservoir 54
VII.—Outlet of Kearney Lake reservoir site, on North Piney Creek 58
FIG. 1. Location of water districts in portions of Divisions II and III 17
2. Irrigation systems on Clear Creek and tributaries 29
3. Discharge of Clear Creek, near Buffalo, Wyoming, for 1894, 1896, and 1897 31
4. Ditches diverting water from Piney Creek across Massacre Hill divide to Prairie Dog Creek 35
5. Location of ditches on tributaries of Tongue River, Division II, district 4 44
6. Location of ditches on North Fork of Tongue River, Division II, district 5 46
7. Dome Lake reservoir 56
8. Lakes at head of Piney and Goose creeks 57

LETTER OF TRANSMITTAL.

DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
DIVISION OF HYDROGRAPHY,
Washington, October 28, 1898.

SIR: I have the honor to transmit herewith the manuscript for a paper entitled Water-Right Problems of the Bighorn Mountains, by Prof. Elwood Mead, State engineer of Wyoming. This paper calls particular attention to the complications arising in the distribution of water as a result of the haphazard construction of small irrigation ditches. The problems encountered in this region are typical of those which are to be met in nearly every State of the West, or which will be met in the near future. The difficulties found in the area described are accentuated by the diversion of water from one stream across divides into other natural drainage lines, thus connecting and greatly complicating the water rights of one individual with those of others. The calling of public attention to these conditions will go far toward arousing enlightened sentiments in behalf of more comprehensive laws in other States and should bring needed support to the efforts of officials in their attempts to distribute equitably the waters of the flowing streams.

Very respectfully,

F. H. NEWELL,
Hydrographer in Charge.

Hon. CHARLES D. WALCOTT,
Director United States Geological Survey.

A NORTH SIDE OF CLOUD PEAK

B. BIGHORN MOUNTAINS AS SEEN FROM BUFFALO, WYOMING

WATER-RIGHT PROBLEMS OF THE BIGHORN MOUNTAINS.

By ELWOOD MEAD.

INTRODUCTION.

The Bighorn Range is the most impressive feature in the landscape of northern Wyoming, and its scenic beauties are made the more attractive by the striking contrast they afford to the surrounding region. The traveler from the East or the South finds the clear, cold, perennial streams which flow from its snow-clad summits a grateful relief from the alkaline pools or dry sand channels which have to be largely relied on when journeying toward them. The lofty and rugged pinnacles of Cloud Peak (shown in Pl. I, *A*) are made all the more commanding because the bad-land hills, which form the summit of the Cheyenne watershed, are so commonplace and unattractive. West of the range is the Bighorn Basin, the lowest and most arid section of the State, where the dusty roads and gray stretches of sagebrush make a traveler look with longing at the snow-crowned, forest-clad slopes of the mountain barrier to the east.

In the arid States mountains, not plains, control agricultural development, and this isolated barrier, which rises near the middle of the northern boundary and extends southeast nearly to the center of the State, has done more to people the northern half of Wyoming than all other influences combined. Without it the section, now gridironed with ditches and supporting about one-fourth the population of the State, would be an open range supporting a few migratory flocks of sheep and herds of cattle. The latent wealth of the few hundred square miles of rocky, barren, and almost unoccupied land surface, over 8,000 feet above sea level, is far greater than that of any equal area in the valley below. This region gathers and stores the moisture which alone gives value to the land below. The perennial streams thereby created have, in their diversion and use, given employment to more people, attracted the investment of more capital, and created more problems to tax the wisdom of the lawmakers than has all the unimproved unirrigated farming land in the State.

The ease and cheapness with which the streams can be diverted, the fertility of the soil, and the exceptional value of the surrounding grazing land have made this section an attractive location for the home-

seeker of limited means. It is a region of small ditches and individual appropriators of water. On the eastern slope appropriation began before there were any laws governing the recording or establishment of rights thereto, while the isolation of the early settlers made them disregard or give little heed to water-right problems until the needs of users began to exceed the available supply; since then the multitude of rights, resulting from the haphazard location of ditches, has made a satisfactory settlement of many of these problems unusually difficult. Before discussing these problems a brief review will be given of the progress made in the twenty years which have elapsed since Manlius Redmond, a settler on Clear Creek, built the first ditch and became the pioneer farmer of the northern half of the State.

At that time the nearest railway station in the State was Rock Creek, on the Union Pacific, nearly 300 miles away. There was not a flour mill in the State, and the long, hazardous, and expensive trip necessary to secure the plow which turned the first furrow and the food for the men who worked on it added greatly to its cost. Reclaiming the desert under such conditions had many drawbacks, and the earlier ditches were of the crudest and simplest character. There was no attempt at any comprehensive projects. Each irrigator was a law to himself. Cooperative ditches or canals were rare exceptions. This explains the large number of ditches of record, and is the cause of many of the obstacles to the satisfactory division of water which confront those charged with this duty.

NUMBER OF APPROPRIATIONS AND ACREAGE RECLAIMED.

The records of the State engineer's office show that there are 1,051 adjudicated rights to the water flowing out of these mountains. There are also 269 claims which have been recorded and approved, but not adjudicated. In addition there are probably 100 ditches using water for which no claim has been filed. The adjudicated rights describe 139,478 acres of land to which these rights are attached in the orders of the board of control establishing them, and there are appropriations from Crazy Woman Creek aggregating 925.25 second-feet where the land irrigated is not described. Four flour mills have rights to water for power purposes aggregating 324.50 second-feet, and the several cities and towns of this region have adjudicated rights for power and domestic purposes amounting altogether to 80.6 second-feet.

Along the northern end of the range some promising placer fields have been discovered, and rights to 137.6 second-feet have been acquired with which to work them. The total volume of the adjudicated rights (3,455.4 second-feet) is in excess of the low-water discharge of the streams against which they are held, but is below the maximum discharge, so that the securing of a stable and adequate water supply for many of the irrigators holding adjudicated rights is a question of

storage. While all of the rights for irrigation, established by the board of control, are based on State surveys of the ditches and on sworn statements of the acreage irrigated by the appropriators, there is no question that these statements are somewhat in excess of the truth. Irrigation and reclamation are elastic terms. Spreading water over land to increase the growth of grass for pasturage purposes is irrigation and is so held by the board of control, but it is not the complete reclamation that is accomplished by cultivation. The tendency to augment the acreage actually watered is so common as to lead to the belief that it is unconscious. In the absence of exaggeration so gross as to constitute an injustice to other users, such a claim usually passes without protest unless it includes land which the State engineer's surveys show to be not susceptible of irrigation. The total acreage irrigated is, therefore, below the figures before given. A deduction of 10 per cent for exaggerated acreages and for areas which have only a surplus or flood-water supply would not be excessive, and would leave 125,000 acres as the actual area irrigated under rights established by the board of control. This is more than half the acreage given as irrigated in the entire State by the Tenth Census.

It is impossible to speak with equal certainty regarding the acreage irrigated under appropriations approved by the State engineer's office, but which have not yet been established by order of the board of control. In making a summary of these rights from the records of the engineer's office, all canceled permits, or those which have not complied with the requirements of the State law, have been excluded. This disposes of all the speculative filings which were made prior to 1894, during the time that no fee was required for the examination and record of applications to appropriate water. Since that time the stringent regulations governing the preparation of these filings have made applications so expensive that the tendency to make these for speculative purposes has almost disappeared. While the applications for permits recently approved do not represent actual utilization, they do represent projects based on reliable surveys, which are being carried out by people who are in earnest and who have sufficient investment in the work to make its completion probable. This is more nearly true of the appropriation of water from the streams of this region than of any other section of the State, as there are no large projects. These recorded and approved permits describe 214,000 acres of land for which irrigation appropriations are claimed, and 34 rights to water for power and domestic purposes.

VALUE OF WATER RIGHTS.

The value of the rights to the water which fills these ditches and fertilizes the land under them is an interesting subject for consideration. That they give to both ditches and land whatever value they have is unquestioned, because an empty ditch and an arid plain are alike

worthless. But while the right to water gives to the land whatever value it has, it does not make all values alike. Cost of maintaining ditches, ease of distributing water, fertility of the soil when irrigated, and the value and extent of the contiguous range are elements which have their influence. The fact that transfers of these rights have not thus far been recognized by the irrigation authorities of Wyoming has prevented any transactions of this character, so that we have to go to surrounding States for statistics on this subject. A recent sale of a right to 78 second-feet in one of the streams of northern Colorado is perhaps the best illustration of the present value of this form of property. In this sale nothing was sold but the right to take water from the stream. The ditches and lands by which it was conducted remained in the possession of the original holders. The right was moved several miles from its original location and required another ditch for the diversion of the water, and yet sold for a little more than $250 per second-foot. Its value was also lessened by the fact that the purchasers knew that the sale would be contested and that the expense of litigation to establish the legality of the transfer would have to be paid by them. The price paid, therefore, was far below what the property would have brought had the sellers been able to give an unquestioned title to the property, and is not, I think, above the value of an unquestioned right in the Bighorn Mountains. If this is true, the value of the adjudicated rights to the water of this range is already over $1,000,000. That this is destined to be greatly augmented in the near future is beyond question. The commercial importance of the water rights, therefore, makes their legality and the measures devised for their enforcement a subject of great economic interest.

BOARD OF CONTROL.

Under the constitution of Wyoming the board of control is intrusted with the supervision and control of all public waters of the State and of their appropriation, diversion, and distribution. Its administrative powers are therefore very broad. It has not only to determine rights to streams, but to enforce those rights afterwards. It has five members. These are the State engineer, who is president, and the four division superintendents. At the outset the board endeavored to outline clearly and definitely its views of what was necessary to complete or perfect a title to water, and so to simplify the methods of taking proof as to enable all water users to know what was required and to prepare and submit it at the least possible outlay. In pursuance of these views the board adopted and published the following governing principles:

1. In order to constitute a valid appropriation the water must have been used for some beneficial purpose, and in the case of appropriation for irrigation the water must have actually been applied to the land.

2. The amount of an appropriation is governed by the volume used and by the requirements of this use—in the case of appropriations for irrigation, by the needs of the land reclaimed.

3. Where reasonable diligence is shown in the construction of ditches and utilizing water, the appropriation dates from the beginning of work on the ditch, the survey to be considered as part of such work; where reasonable diligence is not shown, the appropriation dates from the utilization of the water.

4. Priority of appropriation gives priority of right, except in the case of appropriations made between 1888 and 1891, during which time the law made appropriation for domestic use a preferred priority.

5. Appropriations for irrigation are restricted to 1 cubic foot per second for each 70 acres irrigated. While this does not necessarily apply to lands reclaimed before the enactment of the State law, no appropriation for a larger amount has been made, because in all cases so far considered this volume has appeared ample.

6. Transfers of rights to water made in advance of any adjudication, either by the courts or by the board, are not recognized, the reason being that parties had not such ownership as would enable them to give valid title to the water sold. No transfers involving changes in location or character of use have been recognized.

As the operation of these principles is uniform, and as the facts on which any appropriation rests are in all cases the same, it was possible to prepare a blank form of proof for the guidance of irrigators, and in that way to simplify both the labor of preparing proofs and of the board in their subsequent examination. The following is the form adopted:

PROOF OF THE APPROPRIATION OF WATER.

From ——, Division No. ——.

State your name.

1. Post-office.

2. State the use to which the water has been applied.

3. State the means of diversion employed.

4. If through a ditch, state its name.

5. State (*a*) the date of the survey of the ditch or other distributing works through which the water claimed is diverted; (*b*) the date when the construction of such ditch was begun and when completed.

6. If any enlargements were made, state the date when begun and the date when completed.

7. State the dimensions of the ditch as originally constructed and as enlarged, and if measured by the county surveyor under the provisions of the act of 1886, give the results of such measurements.

8. State the name of person, association of persons, or corporation who built the ditch or canal, and the name or names of its present owners.

9. If water is claimed for irrigation, give the legal subdivisions of land owned or controlled by you for which an appropriation is claimed.

10. State the nature of your title to the above-described land; and if not owned by you, give the name of the owner and the nature of the possessory right which you exercise.

11. State the year when water was first used for irrigation or other beneficial purposes, and by whom.

12. If for irrigation, give the number of acres watered the first year, giving the legal subdivisions on which used and, as near as may be, the acres irrigated in each subdivision.

13. State the number of acres watered each subsequent year, and give the legal subdivisions on which the water was used and, as near as may be, the acres irrigated in each legal subdivision.

14. State the number of acres irrigated from said ditch in 189—, and give the legal subdivisions on which water was used and, as near as may be, the acres irrigated in each subdivision.

15. State the acreage said ditch is capable of watering, give the legal subdivisions of land which it can be made to irrigate, and state who owns said land.

16. State your proportionate interest in said ditch.

(16) The plat prepared by the State engineer is hereby accepted as showing correctly the location of the ditch and the land which can be irrigated therefrom.[1]

17. When does your irrigation season begin and when does it end?

18. If water is used for other purposes than irrigation, state the nature of such use and the time when such use began.

19. How much water is required for such purpose?

20. During what months is the water used?

21. Have you or any other claimant of said appropriation filed a claim to water in the office of the county clerk? If so, give date of filing and the name of the party or parties interested in said claim.

22. Have you had sufficient water each year since the use for which an appropriation is claimed began?

23. If not, state the years of scarcity, the months when the supply was insufficient, and the reason of such scarcity.

I hereby certify that the foregoing affidavit was read to the affiant in my presence before he signed his name thereto; that said affiant is to me personally known (or has been satisfactorily identified before me by ——— ———), and that I verily believe him to be a credible person and the person he represents himself to be; and that this affidavit was subscribed and sworn to before me at ———, on this —— day of ———, 189–.

———— ————,
Division Superintendent.

DEAR SIR: Your attention is called to the inclosed proof of appropriation. It is the intention of the law and also of the board of control to make the adjudication of rights to the use of water as inexpensive to the appropriator as possible. Consequently you are requested to cooperate with the division superintendent to whom you submit your testimony to the extent that you prepare yourself to answer all questions readily and accurately before the day set for submitting said testimony.

Your special attention is called to those questions whose answers indicate the date of your appropriation and use of the water, and to the acreage of land irrigated and description thereof.

By complying with this request you will not only facilitate the taking of testimony, but will insure the correct establishment of the respective rights and possibly prevent expensive and aggravating litigation.

Yours truly,

———— ————,
Division Superintendent.

[1] In case there is objection to the official plat, the parties objecting must, when giving proof, file a written statement of the reasons therefor, and must within thirty days file with the division superintendent a map of said ditch and irrigated lands, with affidavit of surveyor, giving date of survey, attached thereto.

WATER DIVISIONS AND DISTRICTS.

In order that each of the more than 1,000 holders of water rights shall obtain his share of the common supply there must be some officer to see that the rights are enforced and protected in times of

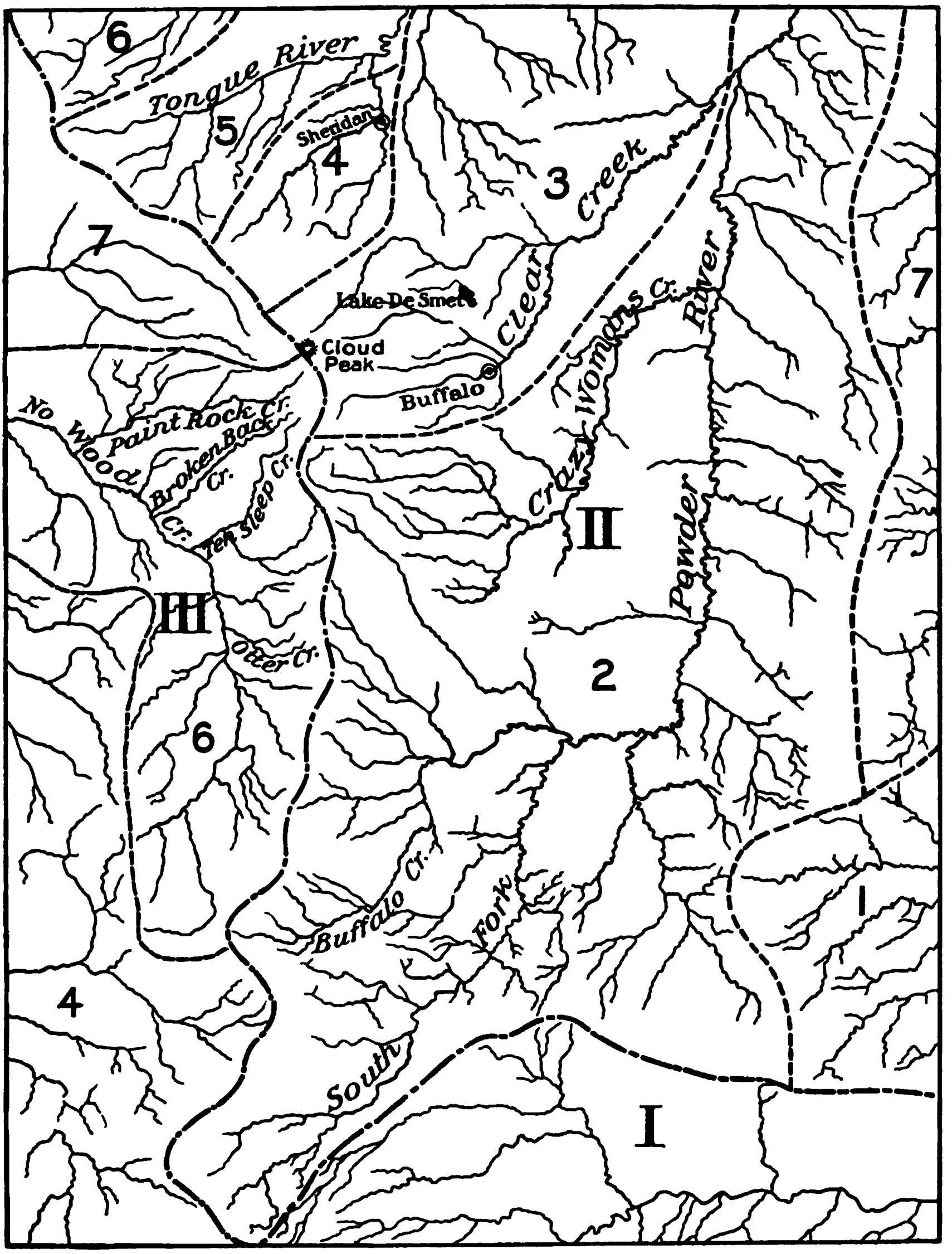

FIG. 1.—Location of water districts in portions of Divisions II and III.

scarcity. For convenience, and in order to make the work more effective, the entire State has been divided into four parts, called water divisions, and these divisions have been subdivided into dis-

tricts, there being at present forty districts in the four divisions. The boundaries of divisions are fixed by statute, those of districts by orders of the board of control, both being determined by drainage lines. The officer in charge of a division is called a water superintendent. He has general control of the work of the water commissioners, which is the title of the officers in charge of districts. The limits of a district are determined by the work to be done. The greater the number of ditches and the more variable the supply the smaller the territory a commissioner can supervise.

The Bighorn watershed forms part of two divisions, the eastern slope being in Division II, and the western in Division III. The portion in Division II is subdivided into five districts, numbered from the south northward 2, 3, 4, 5, and 6. The portion in Division III is subdivided into districts 4, 6, and 7. Fig. 1 shows the location and boundaries of the several districts.

Adjudications of rights to water have been had in districts 3, 4, and 5 of Division II, and in district 6 of Division III. Partial adjudications have been had in districts 2 and 6 of Division II. In the unadjudicated districts, or parts of districts, there is still a surplus water supply, rendering the services of a commissioner unnecessary and permitting further delay in the determination of rights.

APPROPRIATIONS IN DIVISION II.

DISTRICT 2, CRAZY WOMAN CREEK.

In 1889 scarcity of water in Crazy Woman Creek, a tributary of Powder River, led to an adjudication of rights thereto. Wyoming was then a Territory, and the procedure was had under the irrigation law of 1886. Under this law the testimony of appropriators was submitted to a master commissioner, appointed by the judge of the district court, and the final decree was based upon his findings. The outcome was not satisfactory. Water commissioners say that the decree can not be enforced because it does not conform to physical conditions, while late appropriators complain that the earlier priorities are for excessive amounts. The reasons for these objections and the basis of the master commissioner's findings can best be understood from an analysis of the decree. As it deals with the most important and most controverted water-right questions, not of Wyoming alone, but of all the arid States, it merits discussion. The decree, known as "John R. Smith, etc., *v.* Henry W. Devoe, etc.," reads in part as follows:

DECREE OF 1889.

This cause coming on for hearing upon the motion to confirm the report of the special commissioner, made at the present term, and upon the whole case, and the court being sufficiently advised, it is now adjudged that said report of the special commissioner be confirmed, and no exceptions having been filed or taken thereto, that the several findings of the commissioner be approved and confirmed,

and that they be taken, decreed, and held in all respects as the findings of this court in respect to each ditch and canal set out and reported in said report, numbered as to ditches and priorities in the appropriation of water, for beneficial purposes, from Crazy Woman Creek and its several tributaries, respectively, from 1 to 27, inclusively, and that the owner or owners of said several ditches and canals are, and shall be entitled, by original construction and the enlargement of their respective ditches and canals, to priority in the appropriation of water from said Crazy Woman Creek and its tributaries to the extent and in the order hereinafter set out.

PRIORITY NO. 1.

James A. Dowlin, the owner of said ditch by virtue of the construction thereof, shall be entitled, through said ditch, to so much water from Billy Creek, one of the tributaries of Crazy Woman Creek, as may be necessary and useful to irrigate 160 acres of land lying thereunder, not to exceed 8.65 cubic feet of water per second of time, and the same shall be designated and known as priority No. 1.

PRIORITY NO. 2.

That John R. Smith and Agnes D. Smith, the owners of the "John R. Smith ditch" by original construction thereof, shall be entitled, through said ditch, to so much water from Crazy Woman Creek and its several tributaries as may be necessary and useful for the irrigation of 1,200 acres of land lying thereunder, not to exceed 67.03 cubic feet of water per second of time, and the same shall be priority No. 2.

PRIORITY NO. 3.

That the Wyoming Land and Cattle Company, corporation, being the owner of what is known as the "North Fork ditch," taking its water from the North Fork of Crazy Woman Creek, by original construction thereof, shall be entitled through said ditch to so much water from said North Fork of Crazy Woman Creek as may be necessary to irrigate 800 acres of land owned by said company and lying under said ditch, not to exceed 30 cubic feet of water per second of time, and the same shall be priority No. 3.

The wording in the case of the remaining priorities is essentially the same, with the exception of the names of owners, ditches, and other details. The principal facts are given in the table on page 23. In the following table are the dimensions of the several ditches mentioned in the order and decree in this case and given in the report of the special commissioner.

Dimensions of ditches taking water from Crazy Woman Creek.

Priority number.	Name of ditch.	Average dimensions.			
		Top width.	Bottom width.	Depth.	Grade per mile.
		Feet.	*Feet.*	*Feet.*	*Feet.*
1	Billy Creek	7	5	1	7.2
2	John R. Smith	7.5	5	2.75	12
3	North Fork	------	4	1.5	24
4	Harris No. 1	6	4	1.50	6.25
5	Kingsbury No. 1	2	1	1	73.95
6	Halt	5.5	3.5	1	16.5
7	Red Bark	9.5	7.5	1.2	12.7
8	Moreton	6.2	4	1.1	19
9	Cook	10	6	1.8	8
10	North Fork of Crazy Woman	7	4.5	2	4.5
11	Muddy Creek	6	4	1	5
12	Px	7.6	5	1.3	5
13	Kingsbury No. 4	2	1	1	29.94
14	Kingsbury No. 3	2	1	1	29½
15	Kingsbury No. 2	2	1	1	71½
16	Kennedy	*a* 7.1	------	2.3	5.3
17	Dick	8.5	5	1.75	10
18	Burton, Kelly Creek	*b* 1.5	------	1	15
19	Blue Gap	7.5	5.5	1	23
19½	Teddy Miller	13.75	7	2.25	12
20	Fort Collins	20	10	3.7	3.17
20½	North Fork (*c*)	8.5	5.5	1.5	24
21	Devoe No. 1	14	10	2	8
22	Devoe No. 2	10	8	2.5	5.28
23	Canton, Kelly Creek	5	3	1.5	5.28
24	Thompson Brothers	6.5	3.5	1	20
25	Thompson & Matthews	*d* 9	5	1	(*e*)
25½	Moreton enlargement	------	------	1.9	5.28
26	Mitchell & Long	------	6	1.5	4
26½	Kennedy enlargement	11.7	7.1	2.3	24
27	Harris No. 2	------	3	1	6.28

a Average width as originally constructed.
b Average width.
c Enlarged by Covington and Mays.
d Average width as enlarged.
e Grade 4 feet to the mile part of the way and 15 feet for the remainder.

OBJECTIONS TO THE DECREE.

The water described in this decree would suffice for the irrigation of between 50,000 and 75,000 acres of land even under the wasteful methods which prevail. The property disposed of was of great value. If a second-foot of water is worth $250, rights to 900 second-feet are of enough importance to warrant an inquiry into the methods by which they were acquired. Nothing is more indispensable, if we are to avoid disastrous controversies, than to have the acts by which a right to water is secured clearly defined and the limitations on that right definitely prescribed by law. Every user of water wishes to know how the title thereto is to be secured, while everyone interested in the growth and success of irrigated agriculture wishes to be certain that the commodity on which its success depends shall not be wastefully or fraudulently transferred to private or speculative owners. The results of this adjudication have apparently not answered either of the questions clearly or to the satisfaction of those directly concerned.

Controversies over the legality of these rights and over the discretionary authority of the water commissioner in enforcing the decree began the first season of its operation and still continue. That all should have agreed was out of the question. The Territorial law was both indefinite and contradictory in its provisions. Those claiming rights were not agreed either as to the meaning of the law or in their views of an irrigator's needs. Nor was the method of taking proof calculated to disclose the facts on which a just or satisfactory settlement of these rights must rest. There was no measure of the flow of the stream. There was no survey of the ditches, of the lands irrigated, or of the lands which could be irrigated. There was no proof of the actual volume of water diverted or of the needs of the land for which its use was claimed. All that was required in this disposal of public property was for each individual claiming a right therein to file proof of the building of a ditch and his estimate of the volume it would divert. The first objection to this was the lack of knowledge of the claimants themselves. Not one of them knew accurately the carrying capacity of his ditch or the volume needed to reclaim an acre of land. To all the expression "cubic foot per second" was an almost meaningless term. It would have meant just as much if the volume had been expressed in liters. Granting that the desire of all was to claim only what they were entitled to, their success in doing this would be wholly accidental. Nor was the submission of these statements to a judge or a commissioner having no greater practical knowledge than the irrigators themselves a wise provision. The questions to be determined were physical, not legal, and without some knowledge of either the volume which the stream carried or the water used on an acre of land these officers were in no way prepared to pass on the reasonableness of the claims.

In the absence, therefore, of a contest among the claimants themselves, by which the facts would be disclosed, it was possible for claims to be filed and approved which would establish rights to many times the volume used or, on the other hand, which would be below the claimants' real needs. Both of these results actually occurred in this adjudication. In saying this there is no desire to reflect on anyone. The outcome of this adjudication will compare favorably with that of most decrees rendered under this or similar laws elsewhere. What is desired is to explain at the outset that a law which gave the court no power to get at the facts by an impartial examination, but which, on the contrary, made the disposal of a stream depend almost wholly on the knowledge or honesty of those claiming it, could scarcely lead to anything but dissatisfaction, if not injustice.

It would seem that in fixing the volume of these rights the reasonableness of the claims should have been looked into and some uniform test applied by which their legality or necessity could be determined. The importance of this proceeding and its influence on further development was very great. This was a final transfer of a stream from public to private control. It was the surrender by the State of a part of its most valuable property and on the use of which its ultimate population and wealth depend. Realizing this fact, as all thoughtful minds do, it hardly seems reasonable that an ex parte claim should have been accepted without question and made the basis of the grant of a water right. To give every claimant all he asked without inquiry as to his needs or the work actually done to entitle him to anything would seem to be so unwise as to need no discussion. It makes the expression "adjudication" a farce. It will be seen, however, from an analysis of the decree that this is practically what happened. The statute required the evidence of claimants to disclose the capacity of the ditch diverting water and the acreage of land which could be irrigated, and the implication seems fair that the intention of its framers was that this proof should guide the court in fixing the amounts of appropriations. If this is correct, then, under this law, the amount of the appropriator's right to water should have been determined by two facts: First, the capacity of the ditch or canal to divert water from the stream; second, the volume which had actually been applied to beneficial use and the requirements of that use. The language of the decree in its opening paragraph would seem to imply that the construction of ditches alone gave appropriators their rights and that the application of water to a beneficial use was not deemed essential. The portion of the decree on which this statement is based is as follows:

> And that the owner or owners of said several ditches and canals are, and shall be, entitled by original construction and the enlargement of their respective ditches and canal to priority in the appropriation of water from said Crazy Woman Creek and its tributaries to the extent and in the order hereinafter set forth.

If rights were based on the construction of ditches, it would seem that the amounts appropriated should have been fixed by their capacity. To determine whether or not this was done the capacity of these ditches was computed. The dimensions given in the decree were assumed to be correct, and the discharge was determined by the use of Kutter's formulæ, a uniform coefficient of roughness of 0.025 being assumed. This would give a discharge above the actual flow for all except the largest ditches, because the small ones are poorly built, with rough sides and sharp and irregular curves. In the table which follows the computed capacity and the volume decreed are both given, with the difference between such appropriation and the discharge of the ditch:

Capacity of ditches taking water from Crazy Woman Creek and volume of water allotted by decree of 1889.

Priority number.	Name of ditch.	Name of appropriator.	Volume allotted in decree, in cubic feet per second.	Computed capacity of ditch, in cubic feet per second.	Excess of allotment over computed capacity of ditch.	Deficiency of allotment under computed capacity of ditch.	Number of acres watered or proposed to be watered.	Number of acres to each cubic foot per second allotted.	Total volume allotted, in cubic feet per second.
1	Billy Creek	J. A. Dowlin	8.65	16.20	.....	7.55	160	18.5	8.65
2	John R. Smith	John R. and Agnes Smith	a67.03	59.20	7.83	.....	1,200	17.8	75.68
3	North Fork	Wyoming Land and Cattle Co.	30	18.60	11.40	.....	800	26.6	105.68
4	Harris No. 1	W. Harris	12.2	14.25	.....	2.05	150	12.3	117.88
5	Kingsbury No. 1	D. A. Kingsbury	3.75	3.36	.39	.....	160	43.8	121.63
6	Holt	Wyoming Land and Cattle Co.	8.20	12.60	.....	4.40	150	18.3	129.83
7	Red Bark	B. J. and J. M. Scott et al.	37.4	18.70	18.70	.....	800	20.8	167.23
8	Moreton	Moreton Frewen	22.32	28.05	.....	5.73	400	17.9	189.55
9	Cook	Orrin Cook et al	33.55	31.68	1.87	.....	3,300	98.3	223.10
10	North Fork of Crazy Woman.	J. A. Dowlin	28	23	5	.....	300	10.3	251.10
11	Muddy Creek	.....do	8.4	8	.40	.....	300	35.7	259.50
12	Px	C. Basch and O. Speral	17.9	14.74	3.16	.....	200	11.1	277.40
13	Kingsbury No. 4	D. A. Kingsbury	2.35	1.92	.43	.....	300	127.6	279.75
14	Kingsbury No. 3	.....do	2.29	3.03	.....	.78	300	133.3	282
15	Kingsbury No. 2	.....do	3.6	3.04	.56	.....	160	44.4	285.60
16	Kennedy	R. Kennedy et al	32	37.56	.....	5.56	.....	.....	317.60
17	Dick	Powder River Cattle Co., M. Frewen.*b*	12.32	28.48	.....	16.16	600	48.7	329.92
18	Burton, Kelly Creek.	John Burton	3.6	1.80	1.80	.....	160	44.4	333.52
19	Blue Gap	Little North Fork Ditch Co.	26.5	20.15	6.35	.....	1,500	56.6	360.02
19½	Teddy Miller	F. G. S. Hesse	84.45	58.25	26.20	.....	1,160	13.7	444.47
20	Fort Collins	Fort Collins Land and Improvement Co.	210	166.50	43.50	.....	21,000	100	654.57
20½	North Fork	J. May and C. Covington	25	63	.....	38	800	32	679.47
21	Devoe No. 1	H. W. and C. M. Devoe	60.10	72	.....	11.90	2,000	33.3	739.57
22	Devoe No. 2	.....do	78.11	58.05	20.06	.....	3,000	38.7	817.68
23	Canton, Kelly Creek.	F. M. Canton	10.50	10.20	.30	.....	100	9.5	828.18
24	Thompson Bros	F. S. and G. F. Thompson.	17.3	16	1.30	.....	160	9.2	845.48
25	Thompson & Matthews.	.....do	12	10.50	1.50	.....	800	66.7	857.48
25½	Moreton enlargement.	F. G. S. Hesse	45.72	59.33	6.30	.....	4,000	85.3	903.20
26	Mitchell & Long	B. Long, M. F. Mitchell	25	14.40	10.60	.....	1,200	48	928.20
27	Harris No. 2	W. Harris	10	9	1	.....	100	10	938.20

a Based on computation made in State engineer's office. *b* All the land owned by them.

While rights may have been acquired through the building of these ditches, the volumes decreed were manifestly not based on their capacity. Appropriator No. 1, after building a ditch to carry 16 feet, was given only a fraction over half that amount, while in contrast thereto the third appropriator was given 11 feet more than his ditch would divert. The seventh appropriator was given 2 second-feet for each foot the ditch could carry, while the seventeenth was cut down to less than half what had been or could be taken from the stream. Priority No. 18 was favored with a double allowance, while No. 20½ got only half a loaf. Some of the appropriations agree approximately with the volume which the ditch could divert, but the number which are either far above or far below shows that this agreement was accidental and not based on any investigation of this question.

EXCESSIVE AMOUNTS CLAIMED.

Nearly all recent laws and decisions are agreed that simply diverting water does not of itself complete a right to it; that in addition the water so diverted must be applied to some beneficial use. If this test be applied to appropriations for irrigation, the actual acreage reclaimed might properly be taken as the measure by which the volume appropriated should be determined. All of these appropriations are for this purpose, and all except one of them, No. 16, states the acreage to be irrigated, and in the excepted case it is restricted to the land owned by the claimants. A casual inspection of the number of acres irrigated and the amount decreed shows that the need of the land had no weight in fixing these rights. While the measurements of the water used in irrigating an acre of land have not as yet taken the range or embraced all the conditions needed to fix the absolute volume to be used on that area, enough have been made to show the approximate limits of such use. In a series of tests begun by the State engineer and continued by the State University of Wyoming there was not a single instance in which the duty of a second-foot fell below 80 acres. As these tests were made in widely separated localities, embraced a wide range of crops, and were continued for five years, this may fairly be taken as a limit of the actual needs of irrigation, and the State legislature has, since this decree was rendered, made any appropriation in excess of 1 second-foot to 70 acres illegal.

The land along Crazy Woman Creek can be irrigated with less water than is required in some of the localities where the volume used was measured, and there is no reason to question the statement that a duty of 1 second-foot to 80 acres is below rather than above the actual practice along the stream. But whether this be true or not, it is certain that the need of 1 acre is approximately the same as that of every other acre. There is so little variation in the soil and in the crops grown, that sufficient water for one 80-acre tract is enough for any other equal area along the same stream.

This fact could not have been considered in fixing these rights. In the table given, one column gives the acres to be irrigated; in the next column are the acres for which 1 second-foot of water was decreed. It will be seen that the first appropriator is given 1 second-foot for each 18 acres of his land, or at least four times the volume needed, while the fourteenth appropriator is required to spread a second-foot over 133 acres. When the owner of priority No. 20 found he was allowed only 1 second-foot for 100 acres, while his neighbor, owning the twenty-seventh, was given the same volume for 10 acres, he could not be blamed for objecting to the discrimination.

All of these awards are for a continuous flow for the entire year. In practice, however, the use of water in irrigation extends over a period of only three to four months. Assuming one hundred days to be the time of actual need, the irrigator under priority No. 1 is allowed water enough to cover his land to a depth of 10.8 feet, while the irrigator under priority No. 14 can cover his land with only 1.5 feet. The irrigator under priority No. 24 can, if he desires, submerge his farm under nearly 22 feet of water, while the appropriator under priority No. 13 can cover his with less than that many inches.

The excessive volumes of these appropriations make it manifest that the necessities of the land irrigated had no more to do with determining the volume decreed than had the size of the ditches. It is necessary to look further, therefore, to learn the reason for making some rights exceed the capacity of ditches and others fall below, and for allowing some appropriators more water for 80 acres than was given others for 800.

In 1886 a law was passed requiring parties claiming appropriations of water to file in the county clerk's office a statement of their claim. This law required that the statement should contain a description of the ditch, the name of the stream, and the number of acres lying under the ditch and irrigated or proposed to be irrigated. In the same law was a provision for a similar statement of claim for proposed ditches, which required any party intending to appropriate water to file a similar statement with the county clerk. It contained the same provisions as the section relating to existing ditches, with several additional ones relating to protection of existing rights and fixing the time for beginning of work, together with the following ambiguous and misleading clause:

> And from the time of filing any such statement water sufficient to fill such ditch or ditches and to subserve the use or uses aforesaid, if a lawful and just use, *shall be deemed and adjudged to be appropriated.*

Those who know anything about the difficulties which beset engineers in the measurement of water can realize how difficult, if not impossible, it was for farmers having no knowledge of hydraulics to make a correct estimate of the volume they had actually diverted and used, and that it was impossible for them to make an accurate

claim for the volume they proposed to use. A law which would give to each irrigator all he claimed would be an absurdity, if every claim was known to be limited to the claimant's estimate of his actual needs, because of the difference in the capacity of claimants to make a just or accurate estimate; but a law which throws the door open to speculative claims and declares that a speculative absorber of streams can secure an adjudicated right thereto simply by asking for it is an iniquity. The Territorial water law was not framed for that purpose, but it nevertheless opened the door for the water grabber.

Thirty-one claimants to the water of Crazy Woman Creek filed these statements, some being for existing ditches and some for proposed ones. It does not appear from their character that there was any attempt to secure speculative rights, since some of the claimants asked for more water than they needed and others for less. The truth seems to be that the intention of all these irrigators was to comply with the requirements of the law in good faith, but that the volumes claimed had to them no definite meaning, and their statement was entirely unintelligible. There was probably not a farmer along the stream who knew whether he used 1 cubic foot of water or 10. Hence these claims exhibit chiefly the irrigators' lack of knowledge and the necessity, in an adjudication, of some impartial and adequate investigation of the facts on which any reasonable or just right should rest. It was the belief of the holders of these water rights, however, that the filing of this ex parte statement constituted in itself an absolute title to water, and that the further action in adjudicating these rights was only to confirm their title to the volume claimed. The outcome was in accordance with this belief. A comparison of the statements of claims filed in the county clerk's office with the volumes allotted in the decree shows that in nearly every instance they are the same. While a number of those who filed statements of claim do not appear in the decree, and a number of appropriators appear in the decree who did not file claims, there are enough appearing in both to show that the adjudication was almost if not entirely a proceeding to give the makers of these claims all they asked. The following table shows the agreement between the claims filed in 1886 and the appropriations established by the decree of 1889:

Comparison of appropriations under decree of 1889 with original claims filed.

Priority number.	Name of ditch.	Name of appropriator.	Volume allotted in decree, in cubic feet per second.	Volume claimed in statement.
2	John R. Smith	John R. and Agnes Smith	67.03	*a* 80
3	North Fork	Wyoming Land and Cattle Co.	30	55
4	Harris No. 1	W. Harris	12.2	12.2
6	Holt	Wyoming Land and Cattle Co.	8.20	8.20
8	Moreton	Moreton Frewen	22.32	22.32
9	Cook	Orrin Cook et al	33.55	33.55
10	North Fork of Crazy Woman.	J. A. Dowlin	28	28
17	Dick	Powder River Cattle Co	12.32	12.32
16	Kennedy	R. Kennedy et al	32	32
19	Blue Gap	Little North Fork Ditch Co.	26.5	26.5
19½	Teddy Miller	F. G. S. Hesse	84.45	84.45
20	Fort Collins	Fort Collins Land and Improvement Co.	210	210
21	Devoe No. 1	H. W. and C. M. Devoe	60.10	43
22	Devoe No. 2	do	78.11	78.11
25	Thompson & Matthews.	F. S. and G. F. Thompson	12	12
26	Mitchell & Long	B. Long and M. F. Mitchell	25	25
27	Harris No. 2	W. Harris	10	10

a 80 originally; 67.03 later.

If this creek carried enough water for all users, giving each appropriator all he claimed, the decree might not have been open to objection. Unfortunately the stream does not. It may for a few days or few hours each year carry 900 second-feet, although this is to be doubted; but during the latter half of the irrigation season the mean discharge is not one-tenth of this amount, and at times the channel below these ditches is a bed of dry sand. Not one-half the acreage designated in these appropriations has ever been irrigated, nor is there water enough in the stream to irrigate one-half of it without resorting to storage. With storage and with proper economy in the use of water all the land could probably be brought under cultivation, but to secure these there must be some method of restricting appropriators to their actual needs in the first place and some security for the control of stored water in the second. Extravagant appropriation is a prolific source of mischief in preventing both of these desirable results. The holder of a large appropriation claims the

right to control it whether he needs it or not. Parties hesitate to construct storage works to impound water which runs to waste when the title thereto is clouded, as it must be when more water than the stream carries at flood time is decreed to be appropriated.

These excessive rights have been an incessant source of trouble to the water commissioner. The holder of priority No. 2 can close all the ditches above him if his claim is recognized, and if it is not he has a grievance against the commissioner. Two instances have already occurred in which the assistance of the State engineer had to be asked to settle controversies over the right of these holders of a surplus to arbitrarily close the head gates of later appropriators. There is the further danger that these holders of extravagant rights will in time proceed to sell the surplus. If they have the right to do this, as the supreme court of the State has decided in a similar case, the time will come when the owners of the first three appropriations will practically control the stream, and the subsequent rights will not be worth considering. Meantime the water commissioner is forced to be judge, jury, and sheriff in the division of water among users. Under the limitation of the decree which gives to appropriators only the water needed, the commissioner refuses to close the head gates of subsequent appropriators, except in cases of actual need on the part of the holders of prior rights. But this policy is being continually called in question and could be carried out equally well without a decree.

DISTRICT 3.

This district, as shown in fig. 1, includes Clear Creek and its tributaries, and extends from the summit of Cloud Peak on the west to the junction of Clear Creek and Powder River on the east. It is one of the most important districts in the State and one of the most interesting to the student of water-right problems.

FLOW OF CLEAR CREEK.

Measurements of the amount of water flowing in Clear Creek were begun in 1889, their necessity having arisen from controversies over the water rights which the shortage of that year rendered acute. The location of the gaging station is about 4 miles above the city of Buffalo, as shown on fig. 2. The principal diversions above the gaging station are those in the mountains where two ditches carry water across a low divide into the head of French Creek. The measurements made at this point, therefore, do not represent the total flow of the stream, except at such times as the principal ditches are closed. The results of the measurements up to and including 1893 are not available; those for 1894 are shown diagrammatically on page xxxiii of the Second Biennial Report of the State Engineer of Wyoming and are given in the following table. During 1895 observations were

not made because it was impracticable to obtain the services of an observer. The results of the record for 1896 are published in Part

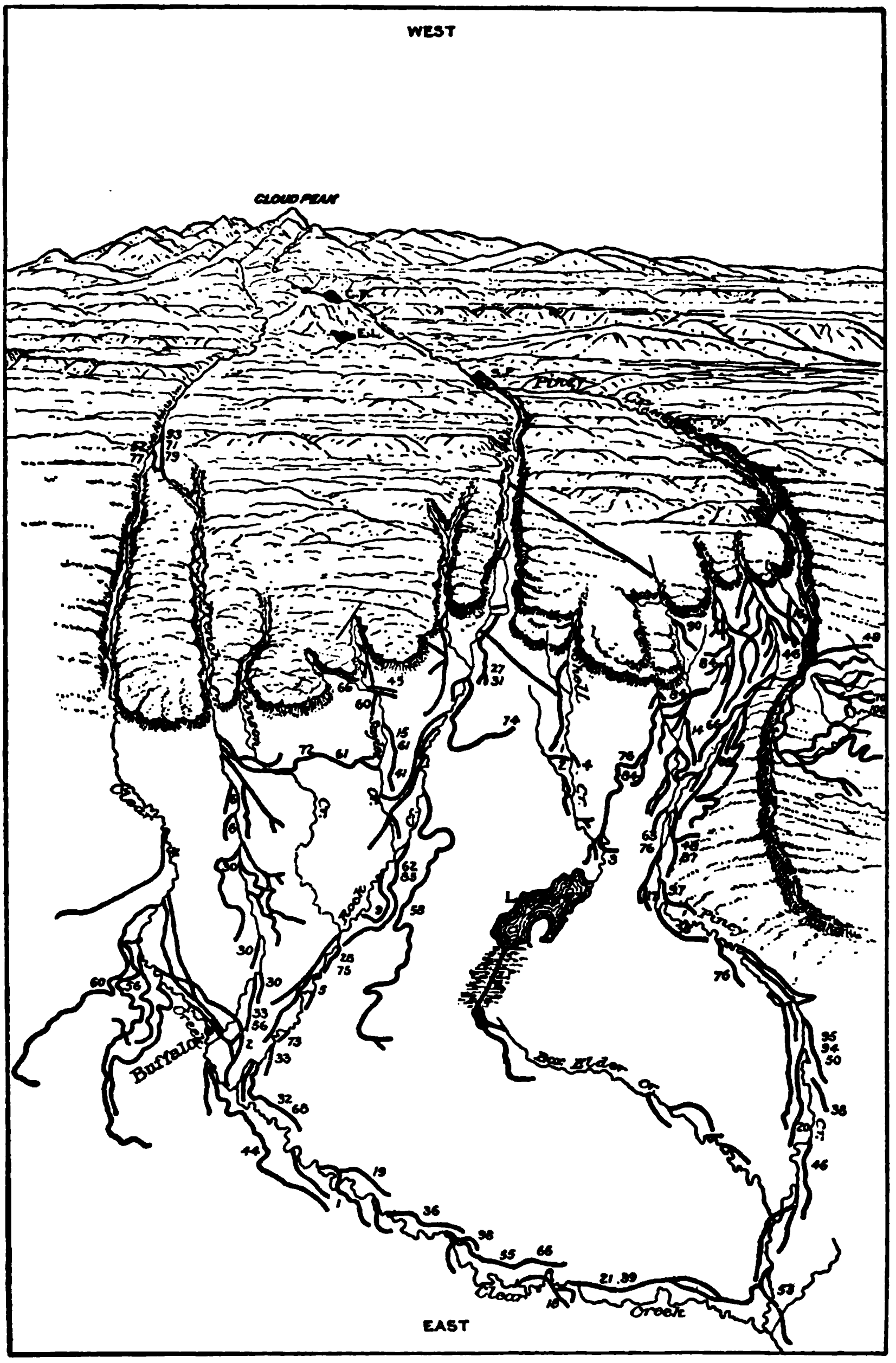

FIG. 2.—Irrigation systems on Clear Creek and tributaries.

IV of the Eighteenth Annual Report of the United States Geological Survey, on page 140, and those for 1897 in Part IV of the Nineteenth

Annual Report, of the Geological Survey, on page 298. The discharge for the three years is also given below and is shown diagrammatically in fig. 3 (page 31).

Estimated monthly discharge of Clear Creek at Buffalo, Wyoming.

[Drainage area, 118 square miles.]

Month.	Discharge.			Total.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth.	Per square mile.
1894.	*Sec.-feet.*	*Sec.-feet.*	*Sec.-feet.*	*Acre-feet.*	*Inches.*	*Sec.-feet.*
June	853	168	283	16,841	2.68	2.40
July	242	62	148	9,100	1.44	1.25
August	80	46	54	3,320	.53	.46
September	80	46	55	3,273	.53	.47
1896.						
May	406	64	139	8,547	1.36	1.18
June	504	82	251	14,936	2.37	2.13
July	323	64	115	7,071	1.12	.97
August	134	40	66	4,058	.64	.56
September	56	40	46	2,737	.44	.39
October 8–19	38	29	32	756	.12	.27
1897.						
May	632	209	345	21,214	3.37	2.92
June	657	189	280	16,662	2.64	2.37
July	246	55	112	6,887	1.09	.95
August	82	39	54	3,320	.53	.46
September	.....	.....	*a* 30	1,785	.28	.25
October	.....	.....	*a* 30	1,845	.29	.25
November	.....	.....	*a* 30	1,785	.28	.25
December	.....	.....	*a* 26	1,599	.25	.22

a Approximate.

Bu
1,

FIG. 3.—Discharge of Clear Creek near Buffalo, Wyoming, 1894, 1896, and 1897.

EARLY RIGHTS AND THEIR ADJUDICATION.

In May, 1878, Manlius Redmond began a ditch to water land along the main stream. It was, so far as the records show, the first attempt at irrigation in northern Wyoming, and the only attempt made that year. Ditches were built in 1879 along nearly every water course of the Bighorn Range, but in the previous year Mr. Redmond was alone. For more than ten years the building of ditches and the extension of the irrigated area made rapid progress, but 1889 was a season of drought, and the shortage on Clear Creek was so marked as to warn the users of water that the limit of profitable reclamation without the aid of reservoirs had about been reached. It also showed the need of an early determination of priorities. In the absence of this, position was everything; the ditch farthest upstream took its full supply

regardless of the rights or necessities of users below, while those farthest down got nothing.

Among the worst sufferers from this condition of affairs was the city of Buffalo. Two large canals, shown in fig. 2, had been built to carry the water of the North Fork of Clear Creek across a divide into French Creek. Their combined capacity was sufficient to drain the stream, and as no seepage returned, the loss to users below was absolute. An adjudication of priorities was begun before the close of the year, but before the preliminary steps had been completed the Territory of Wyoming held a constitutional convention and adopted a provision placing the control of the public waters of the State in the hands of the board of control. The judge of the district court ruled that this action divested his court of jurisdiction, and further progress was stayed until after the admission of Wyoming to statehood and the passage of the State irrigation law.

Under the State law rights to water are determined by the board of control, and an adjudication was begun by measuring the ditches which take water from a stream and by making surveys of the land irrigated or which can be irrigated. The measurements and surveys of Clear Creek and its tributaries were begun in 1891; when completed they were placed in the hands of W. J. Clarke, the division superintendent, whose duty it was to take the testimony of appropriators. Mr. Clarke at once began the taking of testimony, but had not completed this when the board of control met, in February, 1892. On his return from this meeting the division superintendent, who was a stockman, became involved in the "invasion" of Johnson County, as it was called, and all the proofs submitted were lost. It was necessary, therefore, to begin proceedings anew and to take all the testimony over again. Before this work was completed the testimony formerly taken was recovered, and both sets of proofs were before the board of control at its final determination of these rights. The two sets of proofs disclosed many discrepancies and contradictions, and were the cause of several contests, which delayed the final determination of these rights until 1895.

DIVERSION ACROSS DIVIDES.

The map of Clear Creek and its tributaries (fig. 2), shows the location and priority numbers of the several ditches; it also shows that one of these tributaries, Piney Creek, drains a larger mountain area than the main stream and also has a greater discharge. In addition there are the smaller tributaries of French, Johnson, Sayles, Rock, Shell, J. A., Boxelder, Bear Gulch, and Little Piney creeks. Clear Creek and Piney Creek each reach to the summit of the range and drain the entire eastern slope of Cloud Peak, its highest elevation. The other streams are cut off from the perpetual snows and only drain the outlying foothills; hence, while they have an abun-

PINEY CREEK BELOW OUTLET OF CLOUD PEAK LAKE.

dant supply for early irrigation, the late supply is wholly inadequate and, unless reenforced, will only serve for the reclamation of a restricted area. These smaller tributaries are, however, bordered by lands equal in area and of equal value with those along the valleys of the larger ones; hence some method of reenforcing their water supply became an early and important problem. The topography of this region offers unusual opportunities for doing this.

The head waters of French Creek are almost directly below Clear Creek, as its torrential flood comes from the rocky, snow-clad slopes of Cloud Peak. About all that is needed to turn Clear Creek out of its channel is a dam high enough to cause the water to overflow its bank, as the slope is toward French Creek from near its northern margin. One canal built to turn water into French Creek is only half a mile long, while the other, in a less desirable location, is only a mile in length. The map of Clear Creek and its tributaries (fig. 2) shows the location of these two canals, together with the priority numbers 71, 79, and 93 of their appropriations.

The turning of the water from Clear Creek into French Creek and the use of the channel of French Creek as a part of two canal systems created some perplexing problems for the board to solve in the determination of the two classes of rights from the latter stream. Both before and after the construction of the canals to provide this supplemental supply, parties had built ditches and appropriated the original or natural flow of French Creek. Some of these appropriators are interested in the canals in order to obtain an augmented supply, so that in a few cases the same individuals claimed rights to water from two sources through the same ditch to be used to irrigate substantially the same land. Other parties who made no claim to the natural flow of French Creek, but who were part owners in the canals to furnish the augmented supply, had built ditches from French Creek for the purpose of taking out the water turned into it.

There are, therefore, three classes of appropriators along French Creek. First, those who claim the natural flow of the stream; second, those who claim a right to the water of both Clear Creek and French Creek; and third, those who claim the right to use the channel of French Creek as a part of their ditch system, but draw their water supply entirely from Clear Creek. Among these different appropriators a difference of opinion exists as to the volume of water supplied by the natural flow of French Creek. At the time of the adjudication it was urged by the owners of the rights from Clear Creek that the claims of appropriators from French Creek were for more water than the creek carried, that the acreage originally irrigated had been extended by the unauthorized use of a part of the supply turned in, and that the board should restrict these claims. This was not done, because it was found impracticable to measure the flow of French Creek. To have done this would have involved shutting down the

ditches from Clear Creek and the ditches of appropriators above some of the tributaries of French Creek. A single measurement would not be sufficient. In fact, it would take a large number of measurements to reach any definite conclusion.

The demands of the area now under irrigation along the stream are so largely in excess of the natural flow of French Creek that to turn off the water from Clear Creek for a sufficient length of time to permit the measurement of the natural flow of French Creek would have caused the destruction of two-thirds of the crops along the stream. Those appropriators who have an interest in Clear Creek alone or in both supplies naturally objected to such action. The board was therefore compelled to rely on the engineer's surveys and on the proof submitted. Rights were restricted to the actual areas irrigated, but the source of the appropriation recognized was based on statements of irrigators. Those who claimed that their lands were irrigated from French Creek alone were given appropriations for their lands from that source, and those who claimed to have used only the water of Clear Creek were given a right from that stream. Whether or not this was in accordance with the facts will probably never be definitely known. It is one of the instances where haphazard development has reached a stage that renders any accurate settlement out of the question.

The same difficulty now confronts the water commissioner in performing his duties. The two ditches which divert Clear Creek into French Creek are so inaccessible as to make their frequent regulation impossible. Both are mountain ditches with head gates over 9,000 feet above sea level. Their channels are cut among the pines that cover this region and through the rocks from which they spring. To reach them requires a steep and toilsome journey of 15 miles from the mountain's base. They are at an elevation where frost is perpetual and snow almost so. The regulation of such ditches is, therefore, difficult and expensive, and any continuous measurement of the volume they carry is, for the present, out of the question, but the increasing value of these rights will in time render the accurate division of water indispensable. The water from Clear Creek mingles with the natural flow of French Creek until it reaches the first ditches built to divert it. There a part is taken out and carried over the divide between French Creek and Johnson Creek, and serves to reenforce the latter; the ditch is also extended across a second divide, where the remainder is turned into Sayles Creek to reenforce the flow of this stream and of Rock Creek below their junction.

The fluctuations in the flows of French Creek and Clear Creek do not agree, because the latter is fed from the summit of the range, while the former drains a larger area of the foothills region; it rises earlier in the season and also begins to subside earlier, but as the water turned in joins it near its source no measurements to deter-

A

B

RESERVOIR SITES ON PINEY CREEK.

A, At Elk Lake; *B*, At Mead Lake.

mine these variations can be had without an outlay greater than can now be afforded. The practical result is that during the early part of the season all users take from the natural flow of French Creek, while during the latter part nearly all are supplied from Clear Creek. The same conditions exist on Johnson and Sayles creeks, while on Rock Creek there is a third element of uncertainty. This, however, has arisen since the adjudication of rights, and will be described later.

PRAIRIE DOG CREEK.

Referring again to the drainage map of this district (fig. 2), it will be noticed that Piney Creek, which rises in the lakes on the northern

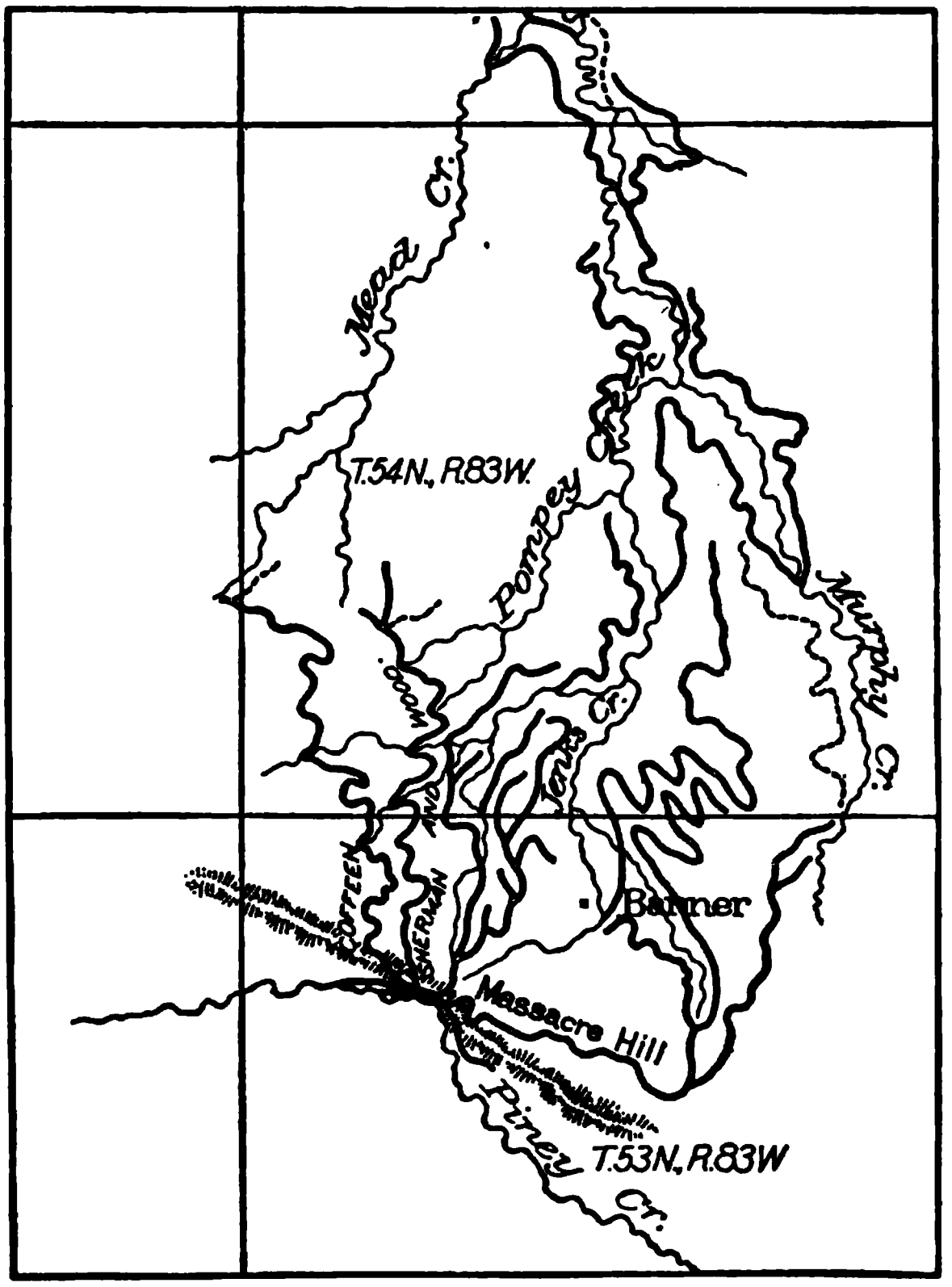

FIG. 4.—Ditches diverting water from Piney Creek across Massacre Hill divide to Prairie Dog Creek.

slope of Cloud Peak (Pl. II), not only drains a large extent of the summit of the range, but effectually cuts off a number of the smaller tributaries of Clear Creek therefrom. Piney Creek, like Clear Creek, receives nearly all its water from one direction. After the stream turns to the north the drainage on the east is into the smaller streams which rise in the foothills below. The most interesting peculiarity of the topography of this stream is, however, the fact that it does

not leave the mountain in a valley, but on a ridge, the mouth of the canyon of Piney Creek being near the summit of the divide which separates the drainage of Tongue and Powder rivers. This divide is an elevated spur of the main range known as Massacre Hill. It leaves the mountain almost at a right angle and extends for a considerable distance eastward. At one point Piney Creek is within 50 feet of its summit. After that it tumbles down into the valley which borders its eastern slope.

Mead, Pompey, Jenks, and Murphy creeks, which form Prairie Dog Creek, a tributary of Powder River, rise on the northern slope of Massacre Hill almost directly opposite the point where Piney Creek so nearly approaches its summit, as shown in fig. 2. Originally this stream was of little importance. It lacked the snowfall necessary to a perennial water supply, and although a few springs are found along its channel, the volume available for irrigation was insignificant. It was an easy project, however, to carry water from Piney Creek over the divide, as shown in fig. 4 and in Pl. IV, and turn it into this stream. Three ditches have been built for this purpose. These ditches follow the prevailing practice of this region in making natural channels a part of the ditch system. The owners of one ditch live along Prairie Dog Creek for 15 miles. The water turned in at the head is taken out by small ditches which divert the creek near their farms. There are 84 appropriations through the ditch of the Prairie Dog Water Supply Company which are diverted from the second stream through a score of smaller ditches.

Before the supplemental water supply had been provided a number of settlers filed on land along Prairie Dog Creek and built ditches therefrom. Some of these settlers became part owners of the ditch to provide an additional water supply; others did not, so that the board again had to deal with three kinds of rights from the same channel—rights to the natural flow, rights to the water turned in, and rights to both combined.

There was a further complication in this case. Prairie Dog Creek is a part of the drainage system of Tongue River, and if drainage lines had to be regarded, it belonged to that district; but since practically the entire water supply came from Piney Creek, the board ruled that water supply rather than the slope of the country should govern its supervision, and this portion of the drainage of Tongue River was made a part of the Clear Creek district.

SUMMARY OF RIGHTS TO WATER.

The diagrammatic map of the irrigation system from Clear Creek (fig. 2) gives the location of the ditches, with the priority numbers of their appropriations. A full list of these is given in the Third Biennial Report of the State Engineer of Wyoming, 1895–96, pages 181 to 194.

NORTH SLOPE OF MASSACRE HILL, ILLUSTRATING EROSION IN DITCHES FROM PINEY CREEK.

The amount of each of the appropriations was fixed by the acreage shown by the proof to have been irrigated, 1 cubic foot per second being allowed for each 70 acres. On Crazy Woman Creek it will be remembered the appropriations were based on the claims filed by appropriators, without regard to the actual use of the water. On French Creek appropriations were based on the areas reclaimed, without regard to the volume of water described in the original statement of claim. The relation of these claims to the actual use of water in irrigation is shown by the comparison of the volume claimed and the volume appropriated on French Creek, as given in the table below.

Volumes appropriated on French Creek as fixed by the order of the board of control and volumes claimed in appropriators' statements.

Priority number.	Name of ditch.	Name of appropriator.	Volume appropriated in decree, in cubic feet per second.	Volume claimed in original statement, in cubic feet per second.
1	Sneider No. 1	Mary L. Carpenter et al	1.64	8
2	Moeller No. 1	Alice S. Rapelyen	1.07	6
2	Moeller No. 2	do	.50	3
3	Moeller No. 3	do	4.28	13.97
4	John A. Fisher No. 1	John A. Fisher	.50	3.35
4	John A. Fisher No. 2	do	.43	23.15
4	Mayhew & Gorgen	Robert Foote	.17	12.40
5, 7	Dundee	do	1.57	8.2
6	Gorgen	Peter Gorgen	.28	13.97
	Total		10.44	88.04

It will be seen from the totals that the appropriations established by reason of beneficial use amounted to only about one-tenth of those claimed. The ratio on all of the streams of this district could not be determined, because many of the claims were for the "unappropriated waters of the stream," designating no specific volume; but if these claims to whole streams were excluded, the claims for a definite volume alone were largely in excess of the actual use, as will be seen by the following comparison, in which all of the claims for indefinite amounts have been thrown out.

Volumes claimed and volumes actually used on streams in water district No. 3, in cubic feet per second.

Name of stream.	Volume used.	Volume claimed.
Total Clear Creek	232.78	853.6
Total Rock Creek	187.64	749.9
Total Sayles Creek	8.18	75.1
Total Johnson Creek	8.13	44.7
Total Piney Creek	334.88	943.8
Total Shell Creek	5.52	68.6
Grand total	772.13	2,735.7

ALLOWANCE FOR LOSS OF WATER IN TRANSMISSION.

Among the interesting questions raised in this adjudication was the extent of the loss of water from canals by seepage and evaporation and the authority of the board to provide for this by an increase in the appropriation.

In the original order of the board no such allowance was made, it being held that 1 cubic foot per second for each 70 acres is so much in excess of the requirements of crops, when the water is distributed with reasonable skill and economy, that it will provide for all necessary loss in transportation.

The Wyoming Land and Cattle Company was, however, dissatisfied with this decision, and on this and other grounds asked for and obtained a rehearing, at which measurements were presented showing the losses taking place between the head gate and the place of use.

The conditions on this ditch are somewhat unusual and need to be stated in order that the results may be properly interpreted. The head gate of the ditch is on what was formerly the Fort McKinney military reservation, near the mouth of the canyon and 3 miles above the town of Buffalo. At the time of these measurements, irrigation from the ditch or above the ditch was not permitted within the reservation limits. After crossing its boundary the ditch passes for several miles around and across a series of ridges on the slopes of which losses by seepage are considerable. In the ravines between these ridges and, in one place, along a slope which the ditch crosses there are beds of sand where the loss from percolation is so great that flumes have been built at these points. For 10 miles the following conditions favor an exceptional loss:

The land through which the ditch is built is not irrigated and local atmospheric conditions favor rapid evaporation.

It is the highest ditch and therefore gains nothing from the irrigation of lands above.

The arid land, the steep slopes, and the stretches of sand all add to the drain by percolation.

The measurements submitted were made in 1896 and 1897 by Fred Bond, a civil engineer of Buffalo, Wyoming, and were made in the following manner: A rectangular weir 4.75 feet in length was placed in the ditch immediately below the head gate, and a similar weir, with a length of 5.75 feet, was placed in the ditch near the lands to be irrigated, 10 miles from the first weir and 56 feet below it, that being the fall of the ditch in this distance. It was found by experiments that it took from eleven to thirteen hours for water to pass from one weir to the other. Hence in making these tests the measurements at the upper weir were taken in the morning and those at the lower weir in the evening, in order to measure as nearly as possible the same supply. The tables which follow give the results obtained, that for August 27 being evidently due to an error in measurement or to disturbance by storms.

Loss of water in transmission through ditch of Wyoming Land and Cattle Company.

Date.	Depth of water on upper weir, in feet.	Discharge, in cubic feet per second.	Depth of water on lower weir, in feet.	Discharge, in cubic feet per second.	Total leakage in flumes, in cubic feet per second.	Total loss, in cubic feet per second.	Loss, in per cent.
1896.							
July 10	0.83	11.448	0.56	7.865	(a)	3.583	31.3
July 11	.82	11.328	.55	7.642	(a)	3.686	32.6
July 13	.76	10.123	.55	7.642	(a)	2.481	24.5
August 25	.65	8.058	.50	6.876	(a)	1.182	14.7
August 27	.62	7.515	(?) .58	(?)9.270	(a)	.....	.....
August 28	.60	7.152	.46	5.877	(a)	1.275	17.9
August 29	.59	6.986	.45	5.671	(a)	1.315	18.9
August 30	.59	6.986	.44	5.547	(a)	1.439	20.6
August 31	.59	6.986	.45	5.671	(a)	1.315	18.9
September 1	.58	6.799	.44	5.547	(a)	1.252	18.5
1897.							
August 8	0.562	6.37	0.34	3.74	0.068	2.56	40.2
August 9	.567	6.69	.34	3.74	.09	2.86	42.8
August 10	.60	7.31	.36	4.06	.125	3.12	42.8
August 11	.68	8.59	.43	5.27	.08	3.24	37.7
August 12	.63	7.70	.38	4.42	.047	3.23	42.0
August 24	.467	5.99	.24	2.24	(a)	3.75	62.6

a Not measured.

It will be seen by examining these tables that the percentage of loss when a small volume of water was carried was much greater than when the depth was increased, seepage and evaporation being apparently about constant. If the board took the maximum loss of over 60 per cent as a basis for an order increasing the original right so as to give 1 second-foot for each 70 acres irrigated at the place of use, it would result in nearly double the original appropriation, while if the minimum loss of less than 15 per cent were made the basis of a new right, this action would require so slight a change as not to warrant a modification of the order.

The board refused to grant the additional allowance. The rehearing established a right to water for an additional acreage and increased the volume to be turned into the ditch. As the loss from seepage and evaporation seems about constant, and does not materially increase when the ditch is full, the larger the amount turned in the smaller the percentage of loss. Hence, with the larger right a minimum loss of less than 15 per cent may be expected.

Fort McKinney has since been abandoned and the reservation will soon be largely irrigated. It is believed that the percentage shown by the measurements will decrease in the future by the building of ditches above this one and the irrigation and saturation of the land below it.

The allowance of 1 second-foot to 70 acres being in excess of actual needs was regarded as sufficient to meet the average loss from the ditch at the present time and ample to meet the ultimate decrease.

The wide variation between percentages in the months when the use is heavy and in the later ones when the use is small, would make the establishment of a satisfactory or just appropriation to meet this loss difficult, if not impossible, while the probability of a progressive decrease in such loss would make it unwise to interfere. Even if the proportion allowed agreed with the conditions when made there is small likelihood of such agreement five years hence.

The board held, therefore, that the making of appropriations in excess of the statutory limit would not be approved; but that where satisfactory proof of unpreventable losses in transit made it apparent that the volume remaining, when the land was reached, would not produce crops, a temporary increase would be provided for by an administrative order to the water commissioner.

OWNERSHIP IN DITCH NOT NECESSARY TO THE ACQUIREMENT OF A WATER RIGHT.

One of the parties submitting proof of the beneficial use of water from Piney Creek was John Leitner, who showed to the satisfaction of the board that he had irrigated and reclaimed 15 acres of land through the Upper Phil Kearney ditch. The board by order estab-

lished the right to water for this land through said ditch. In his proof, Leitner stated that he was a part owner of the ditch through which the appropriation was made, and this claim was not contested in the proceedings before the board. Subsequent litigation arose over the ownership of the ditch, and the court decided that Leitner had no interest in it, but that Thomas J. Foster was the sole owner. Following this decision Foster requested the board of control to amend its records by making him the owner of the water right for 15 acres of land acquired by Leitner through the use of the water in its irrigation. Foster's request was based on the contention that his ownership of the ditch made him the owner of all the water it diverted or of all the rights to water acquired through it.

As it is the belief of the board that rights to water for irrigation, in the State of Wyoming, do not inhere either in the man who filed the claim or in the ditch which carried the water, but in the land reclaimed, the request for a transfer of the right from both the place where acquired and from the man who acquired it did not seem well founded; but recognizing the importance of the question involved, the board, before rendering a decision, asked the advice of the Attorney-General. The letter of inquiry and the reply were as follows:

CHEYENNE, WYO., *March 20, 1896.*

DEAR SIR: The State board of control is in receipt of a petition for review of the order determining the priorities of water from Piney Creek and tributaries, and requesting that the board of control cancel a certain certificate of appropriation of water to John Leitner, guardian, and find that Thomas J. Foster is the sole owner of the Upper Phil Kearney ditch.

The board of control has given careful consideration to this petition, and to the order of the court determining the ownership of the Upper Phil Kearney ditch, and has examined the evidence submitted before said board in the adjudication referred to. We find that the testimony submitted showed that Leitner had irrigated the land for which an appropriation was issued through the Upper Phil Kearney ditch and was entitled to an appropriation therefor, and after a reexamination of the evidence the board is of the opinion that the decree establishing this appropriation was correct.

In awarding an appropriation for the particular land for which an appropriation was claimed by said Leitner, the board did not attempt to determine that he had any ownership whatever in the ditch of Mr. Foster. It simply decided that the evidence submitted showed that the water had been transported through this ditch. The board has always held that its authority is restricted to the examination and determination of the facts showing the application of the water of the State to beneficial use and the rights thereby created, and that it could not determine the property rights in ditches through which the water was conducted. That question has been before the board repeatedly and the decisions have been uniform. In the same way the board is now of the opinion that it is not within its jurisdiction to say that Mr. Leitner is or is not a part owner in the Foster ditch. The decree of the court is regarded as determining that fact, but its validity or effect will not be in any way enhanced, in our opinion, by an assumption on the part of the board that it has authority to in any way determine such facts.

We have, by order, instructed the division superintendent to notify the water commissioner of the effect of the order of the court, and that the amount of the

appropriation through the Upper Phil Kearney ditch has been reduced by such order by the amount necessary for the irrigation of 15 acres, but we do not feel authorized to cancel the certificate of Mr. Leitner. We believe if he can secure satisfactory arrangements for the transportation of the water appropriated through the Upper Phil Kearney ditch by giving suitable compensation to Mr. Foster for the service rendered, or if he can make arrangements for the transportation of the water appropriated for this land through some other ditch, he has a perfect right under our laws to do so, and that the appropriation for the land is not destroyed by the fact that he is not part owner in a particular ditch.

Recognizing the importance of the questions raised, and desiring to avail ourselves of your assistance in their proper solution, we shall be pleased if you can advise us as to whether or not, in your judgment, the board has any authority whatever to determine or pass upon property rights in ditches, and whether or not the decree of the court in this case makes it mandatory upon us to cancel the certificate of appropriation of said Leitner.

Respectfully submitted.

ELWOOD MEAD,
President State Board of Control.

Hon. B. F. FOWLER,
Attorney-General, Cheyenne, Wyo.

MARCH 22, 1896.

DEAR SIR: Replying to your communication of March 20, with reference to the application of Thomas J. Foster for a review of your decision granting a certificate of appropriation to John Leitner, guardian, in which application for review Mr. Foster claims to be the sole owner of the Upper Phil Kearney ditch, and presents a decree of the district court of Johnson County, in an injunction suit brought by Mr. Foster against Mr. Leitner, the decree establishing the ownership of Mr. Foster:

I desire to state that while the State board of control was correct in respecting the decree to the extent of instructing your water commissioner that the amount of the appropriation for the Upper Phil Kearney ditch should be reduced by the amount of water granted therein to Mr. Leitner for the irrigation of fifteen acres, still at the same time you would not be justified in canceling the certificate issued to Mr. Leitner.

While there are allegations in the petition for review to the effect that Mr. Leitner made fraudulent representations to your board with regard to his having an interest in the ditch in question, still, in the absence of an affirmative showing of such fraud, there would certainly be no authority on the part of your board to take this for granted and cancel the certificate in question. The decree of the district court of Johnson County does not indicate this, nor do I understand that affidavits or other proof have been filed at this time for this purpose. The petition which is filed is not in the nature of a petition for rehearing, and I am of the opinion that this question can not be properly reached by your board in any other manner, and unless with the application for a rehearing proof should be presented to your office showing that at the time Mr. Leitner used the Phil Kearney ditch he did so as a trespasser and without the consent of Mr. Foster, then your certificate should stand.

As to whether or not Mr. Leitner is able to use the water in the future is certainly not a question to be considered, as under the statute he is given two years before he can be charged with abandonment, and if during that time he should build a new ditch or arrange with Mr. Foster or some other person to conduct the water from the stream in question upon his land, he would be entitled to appropriate enough to irrigate fifteen acres.

As to the claim that there is a cloud upon the title to Mr. Foster's ditch by your granting the certificate, this is certainly a mistake, and as Mr. Foster would not get the benefit of the water for the fifteen acres which is appropriated by Mr. Leitner, I can certainly see no advantage to Mr. Foster in securing the cancellation of the certificate in question.

Respectfully submitted.

BENJAMIN F. FOWLER,
Attorney-General.

Hon. ELWOOD MEAD,
State Engineer, Cheyenne, Wyo.

The reply confirmed the board's views and the request was refused, Mr. Leitner being given two years in which either to build a new ditch or to arrange with Mr. Foster for the transportation of the water to which he was entitled through the Upper Phil Kearney ditch.

DISTRICT 4.

This district, shown in figs. 1 and 5, includes Big Goose Creek and its tributaries. Little Goose Creek is by far the most important tributary, the acreage irrigated along its valley being greater than along the valley of the main stream. Among the smaller tributaries, Soldier, Rapid, and Beaver creeks are the principal branches of Big Goose Creek, while Jackson, Hanna, Tepe, Davis, Trabing, Kemp, Sackett, and Kruse creeks are all branches of Little Goose Creek, which aid in augmenting its flow and from which lands are irrigated. Here, as in the Clear Creek district, the principal stream drains the summit of the range and cuts off the late water supply of the smaller tributaries, and here also irrigators along these smaller tributaries have taken advantage of the topography of the country to relieve their shortage by carrying water across the divides. This transfer of water from one stream to another has been carried to such an extent in this district that some users get water from half a dozen sources. Irrigators near the lower end of Little Goose Creek have the natural flow of the stream, water from Piney Creek, and from three ditches from Big Goose Creek, making in all five separate sources of supply. These transfers from one watershed to another and this extended use of streams as parts of ditch systems have undoubtedly greatly extended the acreage of land reclaimed, but it has at the same time enormously increased the difficulty of determining and protecting rights. Determining the rights to one stream is hard enough, because of the uncertainty and conflicts of early records, but when these uncertainties embrace four or five sources the problem is infinitely more complex. Take as an illustration the rights to water through the Last Chance ditch. Its head gate is in Little Goose Creek. Whenever there is a surplus in this stream irrigators take from the nearest source. Whenever the supply is inadequate a ditch owned by the same persons diverting water from Big Goose Creek is opened and water is used from that stream. These irrigators have therefore established a right to water

from both streams. The question which confronted the board was, How to frame a decree which would give to these irrigators the right to take water from both streams and at the same time limit it to a single appropriation. If it was absolutely certain that water rights would remain attached to the land where acquired and the decree could have been so worded as simply to give this land whatever water was

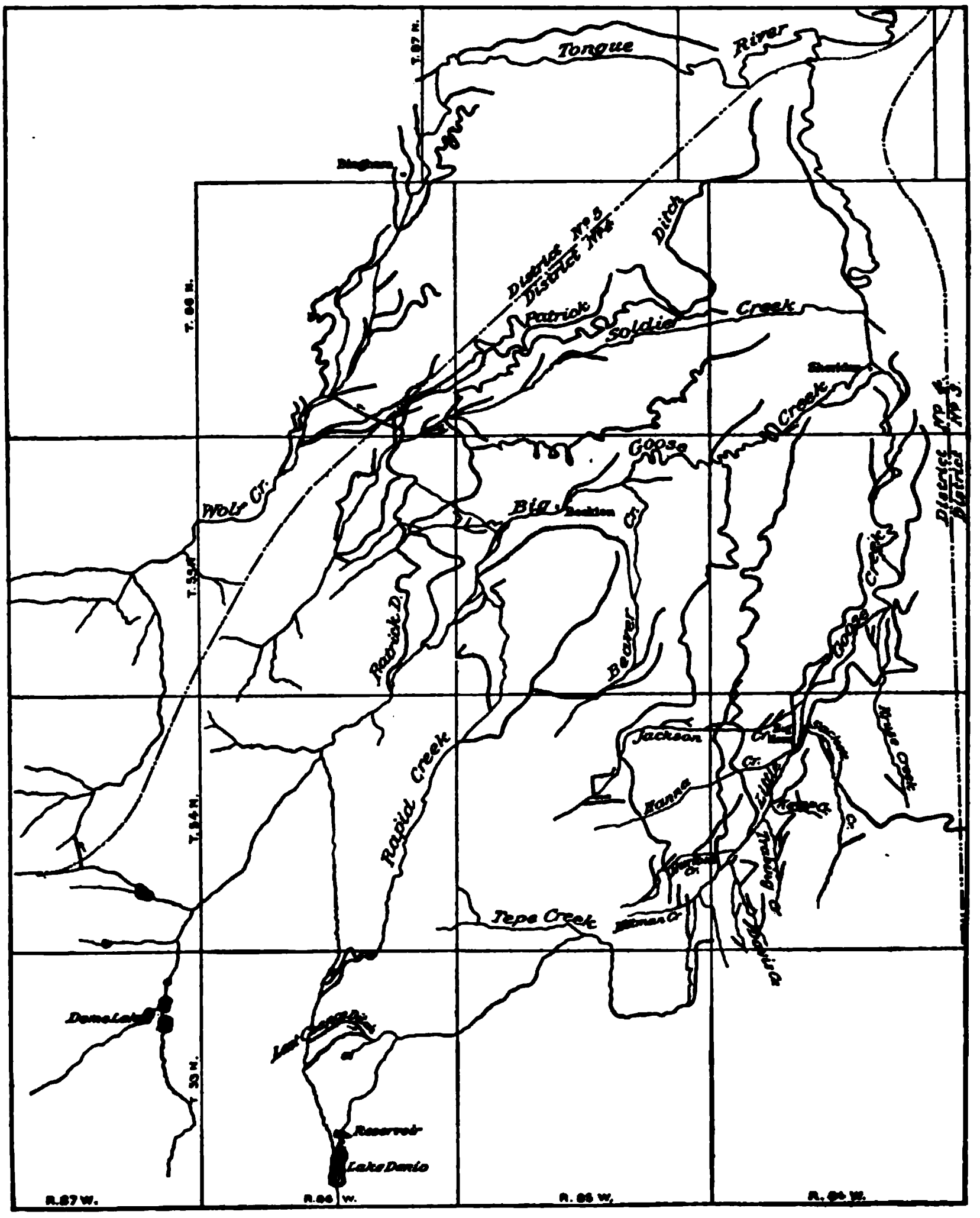

FIG. 5.—Location of ditches on tributaries of Tongue River, Division II, district 4.

needed, there would have been little trouble in preparing the certificates, but the statutes of Wyoming prescribe the form of certificates of appropriation and require the board issuing them to give the volume appropriated in cubic feet per second continuous flow. It was necessary to give the same number of second-feet from each stream, and to

TIMBER FLUME IN CANYON OF TONGUE RIVER

make this continuous, since there is no authority in the law for limiting the appropriation to certain months or to certain portions of the irrigation season. The board endeavored, in framing its order, to prevent any claim to a double appropriation being set up in the future. But its success will largely depend upon the decision of the supreme court as to whether rights acquired under the Territorial law can be sold and transferred to other lands. If this right should be upheld, there is no question that the right to dispose of the appropriations from one of these streams will become a matter of litigation.

The use of two ditches to divert a single appropriation and the use of a natural stream as a part of the canal system made it difficult to fix priorities. Many of the ditches from Little Goose Creek were constructed prior to those which turn water from Big Goose Creek and have different priority numbers. Hence the same tract of land has a divided appropriation—the two parts coming from different sources and having different priorities.

The boundaries of district No. 4 are based on drainage lines, and prior to the beginning of irrigation there was no connection between the streams of this district and those on either side above the mouth of Big Goose Creek. There are three places at which water is transferred from one district to another. It is turned from the North Fork of Big Goose Creek into the head of Wolf Creek in water district No. 5, and by the Patrick ditch from Big Goose Creek across Soldier Creek, and thence into Wolf Creek at a point about 12 miles farther down; and on the south water is turned into Little Goose Creek by one of the canals from Piney Creek, so that drainage lines are being almost obliterated. When the Granger canal is completed there will be a continuous connection by ditches from Powder River on the south to the Montana boundary, a distance of 100 miles, uniting four districts. A summary of the appropriations of water in this district is given in the First Biennial Report of the State Engineer of Wyoming, 1891–92, pages xxv to xxx, and continued in the Third Biennial Report, 1895–96, pages 177 and 180.

DISTRICT 5.

In district No. 5, shown in figs. 1 and 6, the cost of ditches, rather than the adequacy of the water supply, governed the location of the farms first reclaimed. Tongue River, the main stream, has still a large volume unappropriated, which each year runs to waste, but on a number of its tributaries there are more lands under ditch than these streams will fertilize. This condition of affairs is due to the fact that ditch building from Tongue River is expensive, as shown in Pl. V. After the stream leaves the mountains the grade of its channel is very light and the valley narrow. On both sides are high bluffs with very little irrigable land along their slopes, while to reach the table-lands above requires long, crooked ditches with many dikes or flumes, where ravines or tributary streams have to be crossed.

The shortage of water on the tributaries led to early quarrels over its division. Litigation over water rights on Wolf (east of area shown on fig. 6), Amsden, Smith, and Hewes (or Columbus) creeks began when Wyoming was a Territory, but no conclusion had been reached when the State law went into effect. The testimony which had been taken in this litigation was transferred to the board of control, and these streams were among the first to be dealt with by that body. Since the priorities on these tributaries were earlier than the appro-

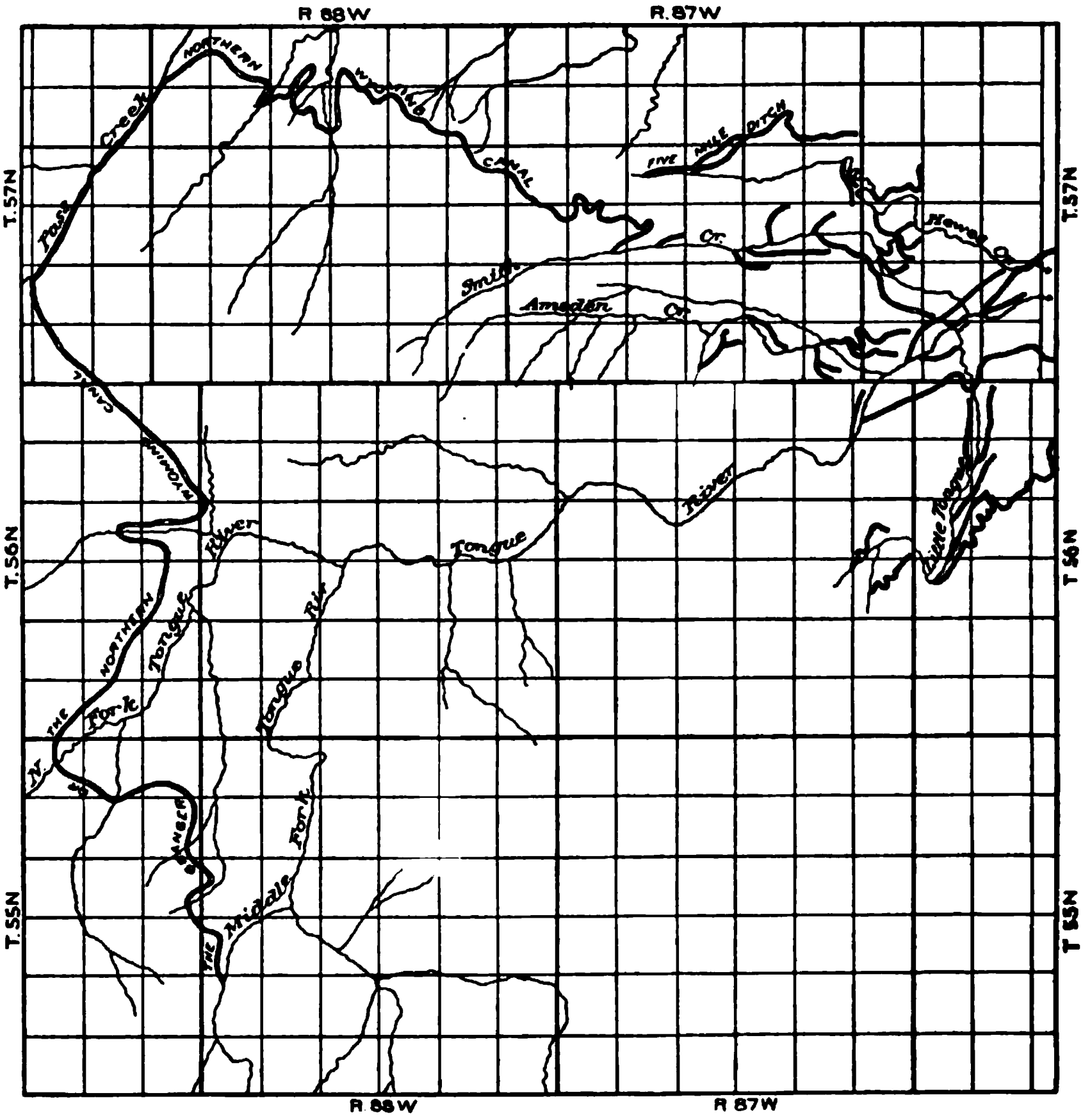

FIG. 6.—Location of ditches on North Fork of Tongue River, Division II, district 5.

priations on the main stream they were independent of any claims on the latter. Hence, in the final determination of these rights, the board of control dealt with each as a separate and distinct drainage basin. The announcement of the policy of the board of control, in limiting water rights to the volume actually used, was not in accord with the views of some of these claimants, who held that their statements of claims described the amounts of their appropriations, and that to reduce these was an encroachment on vested rights.

An appeal from the board's order was taken by the second appropriator from Amsden Creek. This appropriator was allowed 0.86 of a cubic foot per second for the irrigation of 60 acres of land, the location of the land being described. The appeal was based on the claim that water for 150 acres had been appropriated, and made it necessary for the court to rule on the question as to what, under the Wyoming law, constituted an appropriation. The following extract from the proof of appropriation gives the testimony on which the board limited the right to water for 60 acres:

Question. State the number of acres watered each subsequent year, and give the legal subdivisions on which the water is used.

Answer. Claimant increased the amount of land irrigated each year from 1882 to the present time, and now has about 60 acres under cultivation and irrigation.

Question. State the acreage said ditch is capable of watering, and show on a map or plat, on a scale of 2 inches to the mile, the location of said ditch and the land it is capable of watering.

Answer. One hundred and fifty acres.

REMARKS.—Claimant appropriated water sufficient for 150 acres of said land, and now claims water for said land. He does not use said water, has not heretofore, but if farming becomes more profitable he may desire to cultivate all of his land, and his appropriation was made to cover all of said land.

It will be seen from this testimony that only 60 acres had actually been watered, but that the claimant stated it was his intention at some future time, when irrigation became more remunerative, to water more land. The map made by the State engineer's office showed that about 100 acres of land belonging to the claimant could be watered, but that about 50 acres of land belonging to other parties could be watered from this ditch, so that the claim for a possible irrigation of 150 acres from the ditch was correct. The maps and proofs of other claimants showed that about 435 acres of land had been reclaimed, and the actual necessities of this land had more than exhausted the water carried by the stream, so that the resulting shortage had led to litigation over these rights prior to the admission of Wyoming to statehood. This lack of an adequate water supply was shown by the gagings made by the State engineer's office, the volume in July being 5.25 cubic feet per second, while the aggregate of the appropriations made by the board of control on the restricted basis of the necessities of the land reclaimed was 6.21 cubic feet per second. If the claim of an appropriation for 150 acres, instead of 60, had been recognized by the board, the water for the additional 90 acres would have been taken away from lands already reclaimed and from present users, to be held as a speculative property by this claimant until it became valuable enough for him to use, or until, trading on the necessities of those now using it, he could compel them to purchase it from him.

The evils of basing appropriations of water on such considerations would not have ended with this individual. If his belief that he would

at some future time require water enough for 150 acres of land constituted an appropriation, the belief of any appropriator on a stream that he might at some future time use more water would also have entitled him to the full amount of his probable necessities, and appropriations would be fixed not by physical conditions, but by the state of men's minds when filing claims. The first appropriation on this stream was for water sufficient to reclaim 100 acres, but the owners of that ditch had, prior to the adjudication, enlarged it, and had actually reclaimed 110 acres additional, for which they received at the hands of the board of control an appropriation having a later priority. If, however, the contention of the appealing appropriator had been sustained, the appropriator holding the first priority could have maintained that he had intended to appropriate the whole stream and have taken it, while the other five appropriators, including the party appealing from the board's decision, would have been compelled to look to him rather than to the mountains for their water supply.

It seems strange that such an indefinite and unreasonable basis for water rights should ever have had any defenders or received serious consideration; but until the court sustained the board's ruling public opinion in the State was very evenly divided as to the legality of the action. The reason for this lies in the fact that the evils of these extravagant grants are not at once manifest. The term "cubic foot per second" is, to the majority of irrigators, wholly meaningless, and this fact made them unable to appreciate either the effect of an allowance of their claims or the adequacy of the appropriation which the board of control had approved. When a claim had been made for 20, 50, or 100 second-feet of water, and the claimant found that it had been cut down to 1, 2, or 3 second-feet, it was but natural that he should feel aggrieved and be inclined to look with distrust on the assurance that this volume was entirely sufficient to meet all his requirements. The result of basing appropriations on the volumes claimed from Amsden, Smith, and Hewes creeks is not, however, a matter of speculation.

On the last-named stream twenty-eight parties submitted proofs of appropriations, and the surveys of the engineer's office showed that each of them had used water. The aggregate volume of the appropriations approved by the board was 34.8 second-feet, which was less than half the 76 second-feet claimed by the first five. Subsequent experience has shown that the volume fixed by the board's order is more than the stream will furnish, and some of the later appropriators are now building a ditch from Tongue River; but if the stream does not carry 34 second-feet it certainly would not have supplied 76 second-feet, and the allotment of this volume to the first five appropriators would have left nothing for the remaining twenty-three. It is manifest, also, that they have never used more than the stream carries, and of course it is impossible to acquire an appropriation

without ever having diverted or used the water. The injustice of making these claims the foundation of adjudicated rights is strikingly shown in the case of this stream. The claim of the first appropriator was for 21 second-feet, and of the second for 10 second-feet, so that if these two had been given all they asked they would practically have owned the stream.

Smith Creek did not supply enough water to meet the actual needs of users when the priorities were determined. The order of the board limited the rights of all the appropriators to 13.97 cubic feet per second. This was probably in excess of the volume actually used, but it was a great reduction from what was claimed, since that of the first appropriator alone was for 150 second-feet, or more than ten times the volume which the stream carries. The claimant of 150 second-feet received 6 feet, and was indignant because he believed that he had been unjustly deprived of the difference.

LITTLE TONGUE RIVER.

The rights to water from Little Tongue River, the principal tributary of Tongue River, have not as yet been determined. At the time of the adjudication there had not been a sufficiently thorough investigation of the physical conditions to enable the board to reach a satisfactory conclusion as to the merits of some of the questions which must be decided. One of these is a physical problem of great interest. It is a well-known fact that all of the streams draining the eastern slope of the Bighorn Mountains lose more or less water through underground channels. One of the branches of Powder River sinks, to reappear below with diminished volume. The losses on the South Fork of Clear Creek amount to a considerable percentage of its entire flow during the latter part of the irrigation season, and a ditch built to turn water therefrom into Crazy Woman Creek has been a failure, because the water diverted disappeared. But of all these streams the loss in Little Tongue River is the greatest.

During an examination made five years ago a number of funnel-shaped openings were discovered, through which large volumes of water were disappearing, with no evidence of their reappearance. In one case the volume was measured and was found to be in excess of 3 cubic feet per second. In the places examined the water sinks where streams cut across the upturned edges of a limestone stratum of great thickness. Whether the total volume lost from Little Tongue River is greater than that from the main stream is as yet unknown, but the percentage is greater and the loss more apparent. Those dependent on the stream have made many efforts to ascertain the location of these underground channels and close them up, and much has been accomplished in this direction. One of the parties engaged in this work claims that the water thus saved should not be subject to the rights of appropriators of the normal discharge, but

should be wholly independent thereof. In his claim for a separate right and for its adjudication apart from the rights on the main stream he sets forth by affidavit the facts on which the claim is based. The affidavit is here given:

John R. Gatewood, being first duly sworn, deposes and says that he is a citizen of the county and State aforesaid; that he is the person described in the annexed "Application for a permit to divert and appropriate the waters of the State of Wyoming," and that the water which he desires to appropriate from the South Fork of the Tongue River, one of the natural streams of the State, is water which has not as yet been appropriated by any person for "beneficial uses;" that in the said South Fork of Tongue River, back in the mountains, at places described in said "application," there are natural holes on the bottom of the stream through which about 20 per cent of the natural flow of said water, at low water, escapes into the earth, and that, as far as affiant has been able to ascertain, does not again run into said stream or any other natural stream, but is wholly lost; that said affiant believes that he can save said water for beneficial uses; that he is the owner of possessory rights to agricultural lands in said county, and has not water to reclaim the same, and that by being allowed to save this water he verily believed, and does believe, that he can secure said water for said beneficial uses.

A list of the adjudicated rights in water district No. 5 is given in the First Biennial Report of the State Engineer of Wyoming, 1891–92, pages xxxiii to xxxvi and pages xxiii and xxiv. These tables are continued in the Third Biennial Report, 1895–96, page 176.

APPROPRIATIONS IN DIVISION III.

On the west side of the range but little has been done by the State irrigation authorities. Rights have been determined in the sixth district, but not in the fourth and seventh (see fig. 1), there being so large a surplus as to obviate any controversy among users.

DISTRICT 6.

The following order and tabulation gives the rights established in the sixth district and the form in which the entry of the board's action is made in the records of the board of control:

ORDER ESTABLISHING PRIORITIES AND AMOUNTS OF APPROPRIATIONS OF WATER FROM NO WOOD RIVER AND ITS TRIBUTARIES.

In the matter of the determination of the rights of appropriators of water from No Wood River and tributaries, in water division No. 3, Bighorn County, Wyoming.

In this matter the board of control having heretofore, at its regular meeting held on the 21st day of March, 1896, duly made and entered an order for the adjudication and determination of the rights to the use of the waters of No Wood River and its tributaries, in water division No. 3, and directing the State engineer to proceed as soon as possible and survey and measure all the ditches diverting water therefrom;

And it appearing that the State engineer, in pursuance of said order, after giving due and legal notice according to law to all appropriators from said stream and its tributaries, did survey and measure all the said ditches, and prepared and filed complete maps and a report in the office of the said board:

Thereafter N. H. Brown, superintendent of said water division No. 3, after due

and legal notice to appropriators of water fixing the time and place of receiving proof of appropriation from said stream and its tributaries, did appear at the time and place fixed, and did take and receive the sworn proofs and testimony in writing of all persons appearing and claiming rights to water in said stream, and thereafter exposed said proof to public inspection on a day fixed according to law, and said proofs having been examined and no contests having been instituted were thereafter duly filed, with his report and findings, in the office of said board;

And now this matter coming regularly on for hearing and determination by the board of control, upon the records in the State engineer's office and the proofs of appropriation duly taken and submitted by said superintendent, and upon the maps and report of surveys and measurements of streams and ditches duly made by the State engineer and his assistants, and the board having now examined the records in the State engineer's office, the proofs of the beneficial use of water, filed in the office of said board, and having read the report and tabulation and heard and considered the recommendations of said N. H. Brown, superintendent of said division No. 3, that certificates of appropriation be issued, and the board, being now fully advised, finds as follows:

FINDINGS.

The board finds that the appropriations of water determined and established by this order were made from the following-named streams:

No Wood River proper and Bear Creek, Boxelder, Upper or Little Canyon Creek, Crooked Creek, Otter Creek, Spring Creek, Tensleep Creek, Broken Back Creek, Alkali Springs Creek, Paint Rock Creek, all tributaries of No Wood proper.

Cherry Creek, tributary of Boxelder.

North Fork Spring Creek, tributary Spring Creek.

Lower Canyon Creek, tributary Tensleep.

North Fork Broken Back, tributary Broken Back.

Buffalo Flat Creek, tributary Alkali.

Medicine Lodge Creek, tributary Paint Rock.

Coon Holler or Coon Creek, tributary Spring.

That in order to adjudicate and establish the rights of the various appropriators from these several streams it is necessary, in addition to the determination of the order of priority and general priority number of each of the rights to water from No Wood and its tributaries, taken as a whole, for the board to determine and establish the priorities of right growing out of appropriations from each of said streams as between the appropriators therefrom themselves.

The board finds that the rights of appropriators from each of the various tributaries are subject to the rights of prior appropriators on the main stream below, or on the stream into which said tributary flows, and to these rights only.

Subject to the foregoing limitations and conditions, the board finds the name of the appropriators, the priority numbers of said appropriations, the maximum amounts thereof, the uses for which the water was appropriated, and the legal subdivisions of land on which the water appropriated is to be used and to which it is attached are as set forth in the following table.

ORDER.

It is therefore ordered by the board of control that each of the following-named appropriators from No Wood and its tributaries above named do have the use of the water of the stream from which said appropriation was made by him, or them, for the beneficial purpose for which acquired and for no other, and that the names of the appropriators, the priority number of each of said appropriations, the maximum amounts thereof, the names of the ditches or other diverting works through which the appropriation is made, the dates of said appropriations, the beneficial use to which the water is appropriated, and, when for irrigation, the description

of the land to which the water appropriated is attached, shall be the same as stated in the following table under its appropriate heading, which said table is hereby made a part of this order.

It is further ordered that each of the appropriations for irrigation shall be sufficient for the economical irrigation of the land described and no other, not to exceed 1 cubic foot of water per second of time for each 70 acres irrigated.

NO WOOD RIVER PROPER.

Priority number.a		Name of ditch.	Name of appropriator.	Post-office address.	Date of appropriation.	Use to which water is applied.	Amount appropriated, in cubic feet, per second.	Number of acres irrigated.
5	1	S. V	John D. Gill	Redbank, Wyo.	May 1, 1885	Irrigation	0.79	55
11	2	Cornell No. 1	Enoch Cornell	do	Apr. 2, 1886	do	.30	20
12	3	Mead No. 1	John Mead	do	May 1, 1886	do	.15	10
38	4	Spratt	Thos. Spratt	Bonanza, Wyo.	May 18, 1889	do	3.21	225
41	5	Green Spot	Chas. Mills	Redbank, Wyo.	1889	do	.15	10
41	5	Cornell No. 2	Enoch Cornell	do	1889	do	.12	8
42	6	Suez	Taylor Bros	Bonanza, Wyo.	Mar. 15, 1890	do	1.86	130
43	7	Harmony	O. C. Morgan	do	Mar. 20, 1890	do	2.28	160
43	7	do	Henry Jordan	do	do	Domestic and irrigation.	.88	60
43	7	do	Louisa M. Smith	do	do	do	.21	15
43	7	do	A. G. Smith	do	do	do	.53	37
43	7	do	Jas. A. Quiner	do	do	do	.74	50
46	8	Umslopogaas No 2.	A. L. Coleman	Redbank, Wyo.	Nov. 1, 1890	do	.64	45
49	9	Western	L. J. Diehl	Bonanza, Wyo.	Aug. 2, 1892	do	2.78	195
49	9	do	Nich. Carstensen	Hyattville, Wyo.	do	do	1.14	80
49	9	do	Geo. A. Bell	do	do	do	4.08	286
53	10	Ilg	E. M. Ilg	Bonanza, Wyo.	Oct. 16, 1893	do	.71	50
53	10	do	Otto Ilg and Arthur A. Ilg.	do	do	do	.68	48
60	17	Avent	Ira M. Avent	do	July 5, 1895	do	1.71	120
62	18	Cornell No. 2, enlargement.	John Mead	Redbank, Wyo.	Sept. 16, 1895	do	.21	15
63	19	Harmony Mill enlargement.	Henry Jordan	Jordan, Wyo.	Jan. 4, 1896	Mechanical	1.15	.....

BOXELDER CREEK, TRIBUTARY OF NO WOOD RIVER.

1	1	Two Bar	Estate of Harvey Booth.	Redbank, Wyo.	Apr., 1884	Irrigation	0.57	40
16	2	Helms No. 1	Henry Helms	do	Apr., 1886	do	.40	28
21	3	Wells No. 1	Chas. Wells	do	May, 1887	do	.46	32
24	4	Wells No. 2	do	do	Sept. 1, 1887	do	.63	44
25	5	Helms No. 2	Henry Helms	do	Sept., 1887	do	.31	22

UPPER OR LITTLE CANYON CREEK, TRIBUTARY OF NO WOOD RIVER.

13	1	Red Bank	H. A. Richards	Redbank, Wyo.	June, 1886	Irrigation and stock.	4.57	320
40	2	Umslopogaas	A. L. Coleman	do	May, 1889	Irrigation	.50	35
45	3	Rosebud	Harvey Smith	do	Sept., 1890	do	.10	7
55	4	Hillside	C. S. Walu	do	Feb. 16, 1894	do	.93	65
55	4	do	Alex. Arledge	do	do	do	.50	35

CROOKED CREEK, TRIBUTARY OF NO WOOD RIVER.

8	1	F. D. Helmer, or Brunner No. 1.	Frank D. Helmer	Redbank, Wyo.	May 15, 1885	Irrigation	1	70
8	1	Ainsworth	F. S. Ainsworth	do	do	Irrigation and mechanical.	1.14	80

a The first number is the general priority number in reference to the rights to water from No Wood River and its tributaries taken as a whole; the second is the priority number in reference to the rights from each stream.

OTTER CREEK, TRIBUTARY OF NO WOOD RIVER.

Priority number.		Name of ditch.	Name of appropriator.	Post-office address.	Date of appropriation.	Use to which water is applied.	Amount appropriated, in cubic feet, per second.	Number of acres irrigated.
4	1	Grout	C. E. Shaw	Redbank, Wyo.	Apr. 1, 1885	Irrigation	1.05	73½
7	2	Dyson	do	do	May 10, 1885	do	.66	46½
28	3	Daly	do	do	1887	do	.54	38
31	4	Higbie	C. J. Higbie	do	May, 1888	do	2.51	176
58	5	Sawyer	George Sawyer	do	Nov. 7, 1894	do	.71	50

SPRING CREEK, TRIBUTARY OF NO WOOD RIVER.

5	1	Emge & Robinson No. 2.	Wm. Robinson	Redbank, Wyo.	May 1, 1885	Irrigation	0.43	30
5	1	Walu Bros.	R. A. Walu	do	do	do	1.43	100
16	2	Emge & Robinson (Hollywood).	Wm. Robinson	Tensleep, Wyo.	1886	do	.43	30
17	3	Standish & Henderson.	Elmer Chatfield	do	Mar. 20, 1887	do	1.93	135
35	4	Tunnel	A. F. and L. Walu	do	Sept., 1888	do	2.86	200
52	5	Tunnel enlargement, No. 2.	R. A. Walu	do	Sept. 14, 1893	do	.36	25

TENSLEEP CREEK, TRIBUTARY OF NO WOOD RIVER.

2	1	Winn	Milo Burke	Tensleep, Wyo.	Sept. 1, 1884	Irrigation	2.43	160
7	2	Columbian	Milo Burke and Bessie C. Burke	do	May 10, 1885	do	3.00	210
10	3	Bay State No. 1	Bay State Cattle Co.	do	1885	do	1.57	110
22	4	Burke	Milo Burke	do	Aug. 1, 1887	do	.43	30
30	5	Perfection	Fred G. S. Hesse	Buffalo, Wyo.	Apr. 10, 1888	do	7.14	500
44	6	Bay State No. 2	Bay State Cattle Co.	Tensleep, Wyo.	May, 1890	do	.43	30
48	7	Wyman	S. A. McLaughlin	do	July 2, 1892	do	1.14	80

BROKEN BACK CREEK, TRIBUTARY OF NO WOOD RIVER.

7	1	Carothers No. 2	Ed Carothers	Hyattville, Wyo.	May 10, 1885	Irrigation	.21	15
10	2	Cranky Jack	John D. Hopkins	Tensleep, Wyo.	1885	do	1	70
18	3	Hardscrabble	W. R. Williams	do	Mar. 25, 1887	do	.64	45
28	4	Carothers North Fork.	Ed Carothers	Hyattville, Wyo.	1887	do	.09	6
28	4	Carothers No. 1	do	do	1887	do	.36	25
28	4	Carothers No. 3	do	do	1887	do	.29	20
29	5	North Fork	John D. Hopkins	Tensleep, Wyo.	Apr. 1, 1888	do	.71	50
41	6	Dry Fork	H. E. Miller	do	1889	do	.08	5
47	7	Carothers No. 5	Ed Carothers	Hyattville, Wyo.	1890	do	.43	30
47	7	Carothers No. 6	do	do	1890	do	.08	5
47	7	Carothers North Fork No. 1.	do	do	1890	do	.06	4
57	8	Williams	W. R. Williams	Tensleep, Wyo.	July 10, 1894	do	.29	20

PAINT ROCK CREEK, TRIBUTARY OF NO WOOD RIVER.

6	1	Big Bear	David Matthews	Hyattville, Wyo.	May 2, 1885	Irrigation	.43	30
6	1	do	John Luman	do	do	do	1.14	80
14	2	Meyers	H. W. Meyers	do	Sept. 11, 1886	do	.96	67
14	2	do	John Weintz	do	do	do	.15	10
14	2	do	Lee Nansell	Bonanza, Wyo.	do	do	.86	60
19	3	Luman & Allen	John Luman	Hyattville, Wyo.	Apr. 8, 1887	do	.83	58
19	3	do	Jas. D. Allen	do	do	do	.89	62
23	4	Bernstein	Clara F. Collins	Basin, Wyo	Summer, 1887.	do	.86	60
27	5	Elk	Abraham Gotwals.	Hyattville, Wyo.	Fall, 1887	do	2.86	200

PAINT ROCK CREEK, TRIBUTARY OF NO WOOD RIVER—Continued.

Priority number.		Name of ditch.	Name of appropriator.	Post-office address.	Date of appropriation.	Use to which water is applied.	Amount appropriated, in cubic feet, per second.	Number of acres irrigated.
27	5	Elk	John Luman	Hyattville, Wyo.	Fall, 1887	Irrigation	2.64	185
27	5	do	Jas. D. Allen	do	do	do	1.43	100
28	6	Bernstein No. 1	Estate of Fred Bernstein, D. B. Stanton, agent.	Basin, Wyo	1887	do	5	350
33	7	Military	T. F. Nelson	Hyattville, Wyo.	May, 1888	do	.54	38
37	8	Go Ahead	Willis J. Booth	do	May 1, 1889	do	1.79	125
37	8	do	H. D. Hendricks	do	do	do	1.57	110
37	8	do	T. F. Nelson	do	do	do	.43	30
50	10	Shuck & Wilson	Zelotes Wilson	do	Mar. 20, 1893	do	.79	55
50	10	do	Asa Shuck	do	do	do	1.71	120
54	11	Rinehart	Dan H. Rinehart	do	Jan. 23, 1894	do	.18	12
56	12	Hyattville	S. W. Hyatt	do	July 2, 1894	do	1	70
56	12	do	D. W. Hunsinger	do	do	do	.86	60
59	16	South Side	Lee Nansell	Bonanza, Wyo.	July 5, 1895	do	.43	29.8
59	16	Weintz	John Weintz	Hyattville, Wyo.	do	do	1	70
59	16	do	H. W. Meyers	do	do	do	.51	36
59	16	do	Nora O. Meyers	do	do	do	.50	35

CHERRY CREEK, TRIBUTARY OF BOXELDER CREEK.

61	1	Helms No. 3	Henry Helms	Redbank, Wyo.	July 11, 1895	Irrigation	.26	18

LOWER OR BIG CANYON CREEK, TRIBUTARY OF TENSLEEP CREEK.

8	1	Hunsinger No. 1	Jacob Hunsinger	Tensleep, Wyo.	Oct. 15, 1894	Irrigation	2.28	160
15	2	Hunsinger No. 2	do	do	Oct. 1, 1886	do	2.64	185
51	3	Canyon Creek Ditch.	Frank M. Simmons (C. E. Shaw, agent.)	do	Sept. 4, 1893	do	3.64	255

BUFFALO FLAT CREEK, TRIBUTARY OF ALKALI CREEK.

36	1	Buffalo Flat	John J. Smith	Hyattville, Wyo.	1888	Irrigation	.93	65

MEDICINE LODGE CREEK, TRIBUTARY OF PAINT ROCK CREEK.

9	1	George Bayne	D. V. Bayne	Hyattville, Wyo.	May 10, 1885	Irrigation	3.19	223
9	1	do	Estate of George Cassell, F. P. Carr, administrator.	do	do	do	2.53	177
10	2	Wickwire	Byron Wickwire	do	1885	do	.36	25
20	3	Allen & Nelson	Theodore F. Nelson.	do	Apr. 10, 1887	do	1.10	77
20	3	do	Jas. D. Allen	do	do	do	.87	61
26	4	Highland	Lorenzo D. Walu	do	Nov., 1887	do	.49	34
26	4	Walu No. 2	do	do	do	do	.57	40
32	5	Hyatt No. 2	Saml. W. Hyatt	do	May 10, 1888	do	1.21	85
34	6	Anthony	Byron Wickwire	do	Sept. 20, 1888	do	.08	5
34	6	do	David Matthews	do	do	do	3.50	245

COON HOLLER OR COON CREEK, TRIBUTARY OF SPRING CREEK.

39	1	Dutch	John J. Smith	Hyattville, Wyo.	May 17, 1889	Irrigation	.26	18

BEGINNING OF CONSTRUCTION OF DAM AT NORTH END OF DOME LAKE RESERVOIR

It is further ordered that certificates of appropriation be issued to the said appropriators in accordance with the provisions of the foregoing findings and order.

In witness whereof, the president of the State board of control has hereunto set his hand this 10th day of March, A. D. 1898.

RESERVOIRS.

By drawing on the larger streams when the smaller ones were exhausted it has been possible to utilize a large percentage of the flow from the east side of the range without resorting to storage, but the time is approaching when storage will be necessary if the reclaimed area is to be extended. Storage has been somewhat delayed, because there is no law at present defining and protecting rights to stored water. This is one of the legislative questions to be dealt with in the near future. Much can be done whenever it becomes necessary. The sites for mountain reservoirs are both numerous and valuable. From the summit of Cloud Peak over 100 mountain lakes can be counted, and a large percentage of these will in time be utilized.

Actual construction has begun on only one of these reservoir sites—Dome Lake. The location of this lake is shown in fig. 5, and a detailed sketch of the lake and surroundings is given in fig. 7. The elevation of the lake is 8,720 feet, as determined by the topographers of the United States Geological Survey during the season of 1897. The area of the water surface is 320 acres, the average depth 20 feet, and the total flow of water 6,400 acre-feet. The estimated cost of the reservoir is $50,000. The improvements have been made with the double object of storing water for irrigation and of making this point an attractive summer resort.

The importance of the lakes on the head waters of Piney Creek is clearly shown in the able report of Capt. Hiram M. Chittenden, giving the results of his preliminary examinations of reservoir sites in Wyoming and Colorado.[1] The relative location of these lakes is shown on the Cloud Peak topographic atlas sheet of the United States Geological Survey, the area being mapped during the field season of 1898. From a report by Mr. François E. Matthes, the following facts concerning South Piney Creek have been obtained:

The South Fork of South Piney Creek flows from the snow banks and glaciers east of Cloud Peak, and has therefore an abundant water supply throughout the year. Its valley, above the point where the ditch to Rock Creek begins, is the bed of an ancient glacier, and is thickly covered with morainal deposits of irregular disposition, giving rise to a remarkable number of lakes of all sizes. Among these are Cloud Peak Lake and Mead Lake, shown in fig. 8, both of which

[1] Preliminary examination of reservoir sites in Wyoming and Colorado, by Capt. Hiram M. Chittenden, with monograph on Reservoirs and their effects on the floods of the Mississippi system, by James A. Seddon: House Doc. No. 141, Fifty-fifth Congress, second session. Washington, 1898. 110 pp., 10 folding maps.

have at various times been proposed for reservoir sites. Both are deep and are surrounded by steep mountain sides; the altitude of Cloud Peak Lake is 9,703 feet and of Mead Lake 9,950 feet, approximately. (See Pl. III, *B*.) Unfortunately but one of the two main canyons on the east side of Cloud Peak drains into these lakes. The other (lesser) canyon joins the main canyon half a mile below Cloud Peak Lake.

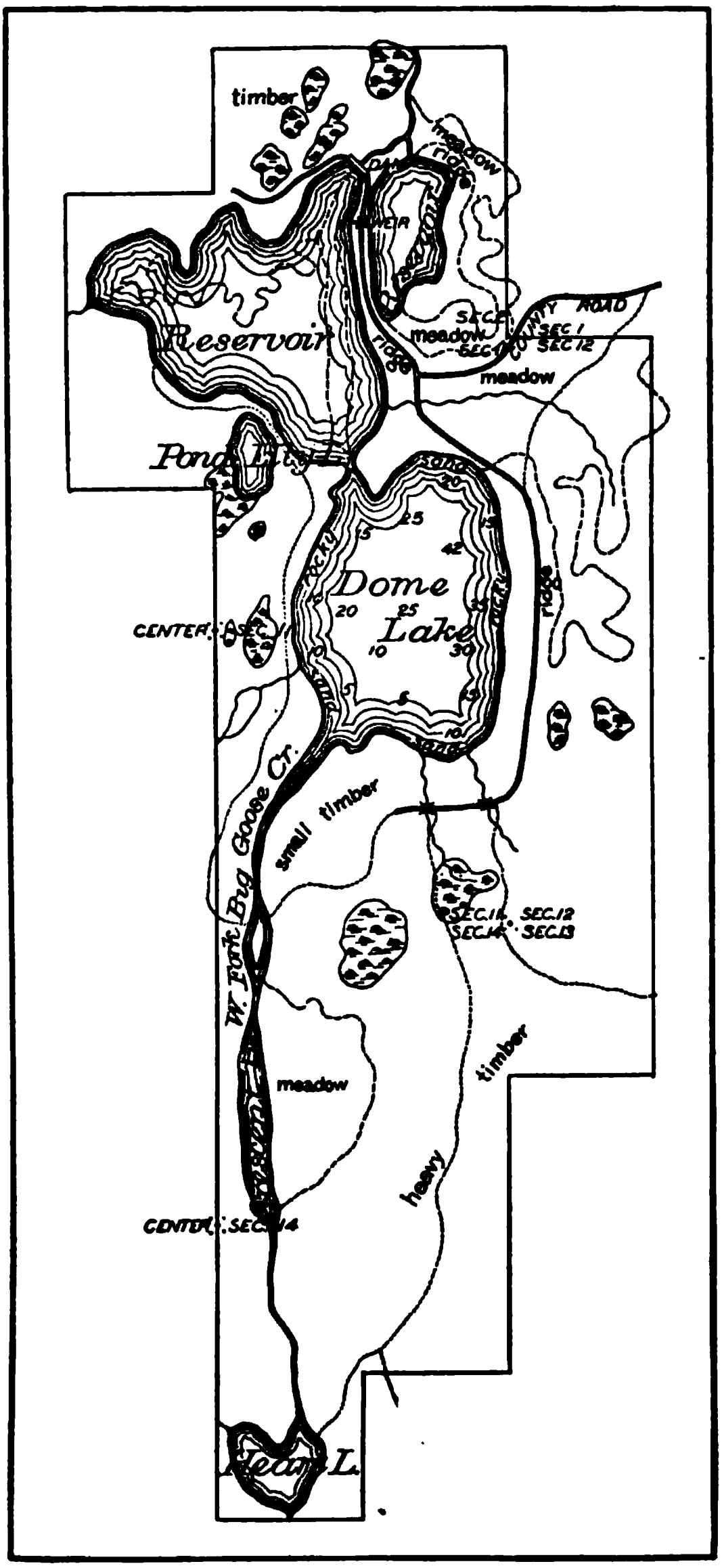

FIG. 7.—Dome Lake reservoir.

Another large body of water, Elk Lake, draining into the South Fork of South Piney Creek, lies on a broad shelf and is very shallow. The lake is at an elevation of 9,850 feet. Its catchment area is very small, almost entirely above timber line, and contains nothing larger than insignificant rills. In spring it probably receives a large amount of water from the melting snowdrifts on the peaks. The outlet of the lake is wide and flat and of a swampy character. The stream at that point is quite small, but increases farther on. It apparently sinks into the ground on leaving the lake, a phenomenon quite common in a country covered with glacial débris. By building a low dam the area of the lake will be considerably increased, but the water supply will be limited practically to that obtained in spring from snow banks which entirely disappear each summer.

The North Fork of South Piney Creek flows through a valley similar

to that of the South Fork. The number of lakes, as shown in fig. 8, is even larger than on that branch, but few are available for water-storage purposes. Among these are the Kearney Lakes, altitude 9,156 feet, in reality one lake, which, however, is fast being converted

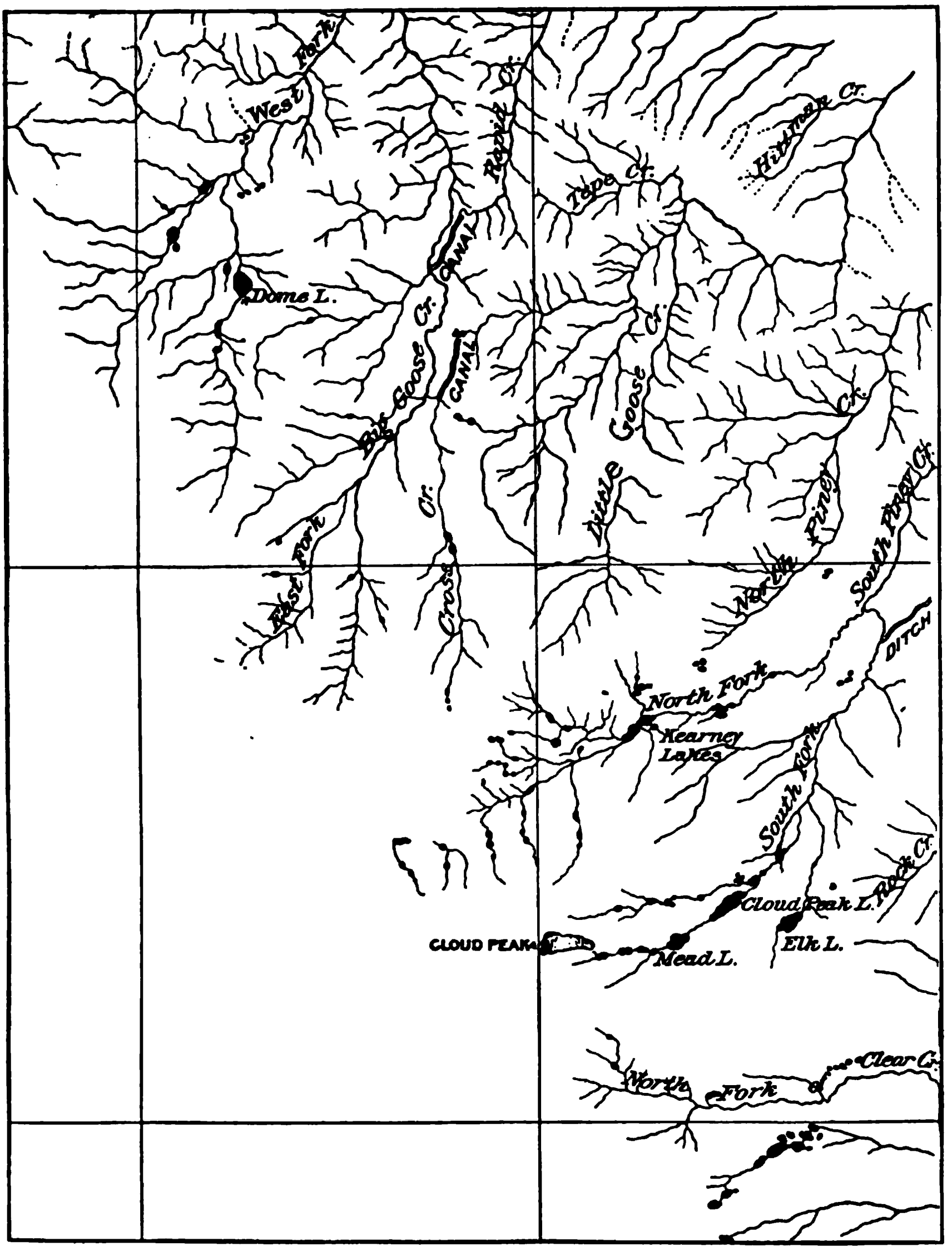

FIG. 8.—Lakes at head of Piney and Goose creeks.

into two separate lakes, as shown on Pl. VII, by the sediment of two small brooks entering near the middle, opposite each other. The twin lakes thus formed are deep and can easily be dammed at the outlet. They receive all the water from the glaciers in the canyons north

of Cloud Peak and that from the perpetual snow banks on the peaks of the main range. It is expected that surveys for a reservoir dam at these lakes will be commenced early next season.

The northern forks only of Clear Creek were mapped during 1898, but a general survey of the entire drainage area revealed the fact that each of the half dozen canyons which form its head waters contains a number of lakes, some of them almost as large as the Kearney Lakes. The entire basin is thickly covered with morainal ridges; it is extremely rough and practically inaccessible.

Sites along Tongue River will serve to increase greatly the acreage that stream will reclaim, while on the western slope the improvement of the lakes on Medicine Lodge and Tensleep creeks will serve not only to double the reclaimed area but to call attention to a region of unsurpassed scenic attractions.

The maps filed in the State engineer's office serve to show the location of the projects on which work was begun and the nature of the improvements proposed.

Names, superficial area, and contents of the reservoirs in the Bighorn Mountains for which permits have been issued by the State engineer.

Name.	Superficial area in acres.	Contents in acre-feet.
Dana reservoir	4	25
Kearney reservoir	146.2	3,801
Dome Lake reservoir	211.2	3,168
Willow reservoir	57.8	650
Barr reservoir	48	450
Treichler & Parsons reservoir	5.1	61.2
Ella reservoir	45	1,000
Denio reservoir	198.75	1,743.75
Cross & Cruse Co. reservoir	21	----------
Elk Lake reservoir	197.55	2,570
Cloud Peak reservoir	170	2,500
South Piney reservoir	95.4	1,050

ADMINISTRATIVE QUESTIONS.

The commissioners in charge of the districts described in this bulletin have to deal with unusual conditions. The division of a stream among users is a difficult problem under the most favorable circumstances, but the commissioners of these districts are confronted with complications seldom encountered in equal measure elsewhere. These are:

1. The interchange of water between streams in the same district and its transfer across district boundaries.

OUTLET OF KEARNEY LAKE RESERVOIR ON NORTH PINEY CREEK

2. The frequent use of streams as part of a ditch or canal and making not one stream but three or four streams part of a single system.

3. The attaching to one piece of land of rights from more than one stream through one or more ditches.

4. The construction of canals to carry water across divides in remote and inaccessible locations in the mountains, thereby rendering the regulation of head gates expensive and difficult and the measurement of stream flow practically impossible.

Even when the streams are gaged and the commissioner knows the supply to be divided he is often unable to perform his work to his own satisfaction or that of irrigators. The wide and rapid fluctuation of streams is to blame for this. From the records of the gagings of Clear Creek, made by the State engineer and the Geological Survey, it is seen that the discharge ranges from three or four times the total volume appropriated to about one-third this volume, and that at times these two extremes are reached within a few days of each other.

The gaging station is below the mountain ditches, and its record does not show what they divert, but it does show how rapid must be the commissioner's movements to protect the rights to the 232 second-feet appropriated. On May 23, 1896, as shown in fig. 3, less than 100 second-feet was passing over the weir; on the 24th there was over 200. On June 3 a flow of 504 second-feet permitted all users to waste water, if they so desired. Three days later the discharge was less than the amount appropriated. On the 19th the flow was 209 second-feet; on the 29th it was 82. The distance from the highest to the lowest head gate on this stream is 50 miles, and an examination of the map (fig. 2) will show the haphazard location of the appropriations and the rapid changes necessary to protect these rights when the demand begins to exceed the supply. The commissioner would have enough to do in times of scarcity to regulate this stream only, but he has in addition to watch the fluctuations of half a dozen others and keep track both of their natural discharge and of the water turned in from other streams.

While doing this he can only estimate the volume to be distributed. From the highest ditch on Clear Creek to the foot of the mountain is a day's journey. It takes half that time to go from the highest land irrigated on Rock Creek to the head gate of the Piney feeder in the mountains along that stream. From the last ditch on Prairie Dog to the first on the stream which supplies it the distance is 40 miles in one direction, and it is an equal distance to the last ditch along the valley of that stream in almost the opposite direction. Without telephone or telegraph connection, the commissioner can deal only with what he sees. Under the circumstances the success achieved has been little less than marvelous.

The water turned from Big Goose Creek into Little Goose Creek enters that stream 9 miles from and 2,000 feet above the land first

irrigated. The head of the ditches can only be reached after a day's journey, and frequent inspections can not be made. Because irrigators can not know the facts, they are all the more likely to resent any interference with their supply. Appropriators of the natural flow are sometimes disposed to believe that those dependent on some other source get more than their share, and vice versa. Users of water along Piney Creek, Big Goose Creek, and other large streams do not look with favor on the diversions into other drainage basins where the subsequent regulation is so expensive and difficult. It is, therefore, a high tribute to the honesty and tact of the commissioners and superintendent to say that they have thus far performed their duties in such a way as almost entirely to avert litigation. To enable them to continue this, however, their labors should be supplemented by comprehensive measurements of the discharge of these several streams. The turning of water across divides and the use of a stream as part of a ditch is no doubt economical, but unless the methods so largely employed here are supplemented by numerous stream gagings, it is hard to see how commissioners are to distribute successfully a supply coming from three or four sources.

Lack of gagings add to the perplexities of the State engineer. It is a part of his duty to refuse permits for additional ditches when the water supply is exhausted. So long as he has no knowledge of the volume being diverted, nor where it goes, he has to depend largely on conjecture. The extensive construction of reservoirs along the channels of these streams which is certain to result in the near future, and the use of their channels to transport the stored water to the place of use, will aggravate these complications. That they can all be removed is not to be doubted, but to accomplish this it will be necessary to have a full understanding of all the conditions, and foremost among these is the amount of water there is to be stored, divided, and used.

INDEX.

Page.

Administrative difficulties, discussion of. 58–60
Amsden Creek, appropriations from..... 46–48
Barr reservoir site, description of..... 58
Big Canyon Creek, appropriations from. 54
Big Goose Creek, appropriations from... 43–45
map showing lakes at head of..... 57
Bighorn Mountains, plate showing view of 11
Billy Creek ditch, irrigation from..... 19, 20, 23
Blue Gap ditch, irrigation from..... 20, 23, 27
Board of control, work of..... 14–16
Bond, Fred, stream measurements by.... 39
Boxelder Creek, appropriations from.... 52
Broken Back Creek, appropriations from. 53
Buffalo, stream measurements near..... 30–31
Buffalo Flat Creek, appropriations from. 54
Burton ditch, irrigation from 20, 23
Canton ditch, irrigation from 20, 23
Chittenden, H. M., cited 55
Clear Creek, measurements of..... 28–30
map showing irrigation systems on .. 29
diagram showing discharge of..... 31
appropriations from..... 31–32, 38
diversion of water from..... 33–35
Cloud Peak, plate showing view of..... 11
Cloud Peak Lake reservoir site, description of..... 55–56, 58
Cook ditch, irrigation from..... 20, 23, 27
Coon Creek, appropriations from 54
Crazy Woman Creek, appropriations from 18–28
Crooked Creek, appropriations from..... 52
Cross & Cruse Co. reservoir site, description of..... 58
Dana reservoir site, description of..... 58
Denio reservoir site, description of 58
Devoe ditches, irrigation from 20, 23, 27
Dick ditch, irrigation from 20, 23, 27
Dome Lake reservoir, plate showing..... 54
description of..... 55, 58
map showing 56
Dundee ditch, irrigation from..... 37
Duty of water, amount of..... 24–25, 38
Elk Lake reservoir site, plate showing .. 34
description of..... 56, 58
Ella reservoir site, description of..... 58
Fisher ditches, irrigation from..... 37
Fort Collins ditch, irrigation from.... 20, 23, 27
French Creek, appropriations from ... 33–35, 37
Gorgen ditch, irrigation from..... 37
Harris ditches, irrigation from..... 20, 23, 27
Hewes Creek, appropriations from..... 46, 48
Holt ditch, irrigation from 20, 23, 27
Johnson Creek, appropriations from..... 38
Kearney Lake reservoir site, description of..... 57, 58
plate showing view of..... 58
Kelly Creek ditches, irrigation from..... 20, 23
Kennedy ditch, irrigation from..... 20, 23, 27
Kingsbury ditches, irrigation from..... 20, 23
Land reclaimed, acreage of..... 12–13
Last Chance ditch, appropriations from.. 43–45
Little Canyon Creek, appropriations from..... 54
Little Goose Creek, appropriations from. 43–45
map showing lakes at head of..... 57
Little Tongue River, map showing ditches from 46
appropriations from 49–50
Loss of water in transmission, allowance for..... 38–40
Lower Canyon Creek, appropriations from 54
Massacre Hill, plate showing view of..... 36
Matthes, F. E., cited..... 55
Mayhew & Gorgen ditch, irrigation from. 37
Mead Lake reservoir site, plate showing. 34
description of..... 55–56
Medicine Lodge Creek, appropriations from 54
Miller ditch, irrigation from..... 20, 23, 27
Mitchell & Long ditch, irrigation from. 20, 23, 27
Moeller ditches, irrigation from..... 37
Moreton ditches, irrigation from..... 20, 23, 27
Muddy Creek ditch, irrigation from 20, 23
Newell, F. H., letter of transmittal by... 9
No Wood River, appropriations from.... 50–52
North Fork ditches, irrigation from 19, 20, 23, 27
North Fork of Crazy Woman ditch, irrigation from..... 20, 23, 27
Otter Creek, appropriations from..... 53
Paint Rock Creek, appropriations from.. 53–54
Piney Creek, plate showing view of..... 32
plate showing reservoir sites on..... 34
diversion of water from 35–36
map of ditches diverting water from. 35
appropriations from 38
map showing lakes at head of..... 57
Prairie Dog Creek, appropriations from. 35–36
map of ditches diverting water to.... 35
Px ditch, irrigation from..... 20, 23
Red Bark ditch, irrigation from..... 20, 23

	Page.
Redmond, Manlius, irrigation by	12, 31
Reservoir sites, description of	55–58
Rock Creek, appropriations from	38
Sayles Creek, appropriations from	38
Shell Creek, appropriations from	38
Smith Creek, appropriations from	46, 48, 49
Smith ditch, irrigation from	19, 20, 23, 27
Smith *v.* Devoe decree, extract from	18–19, 23
criticism of	21–23
Sneider ditch, irrigation from	37
South Piney reservoir site, description of	56–57, 58
Spring Creek, appropriations from	53
Storage, necessity of	27, 55
Tensleep Creek, appropriations from	53
Thompson & Matthews ditch, irrigation from	20, 23, 27
Thompson Bros. ditch, irrigation from	20, 23
Tongue River, map showing ditches from tributaries of	44, 46
plate showing flume in canyon of	44
appropriations from	45–46
Treichler & Parsons reservoir site, description of	58
Underground channels, loss of water through	49–50
Upper Canyon Creek, appropriations from	52
Upper Phil Kearney ditch, appropriations from	40–43
Water districts, boundaries of	17–18
Water rights, value of	13–14
Willow reservoir site, description of	58